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Technology Review

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IS THE CLOUD SAFE?

IT HAD BETTER BE—WE ALL WORK THERE. p36

The Authority on the
Future of Technology
January/February 2010
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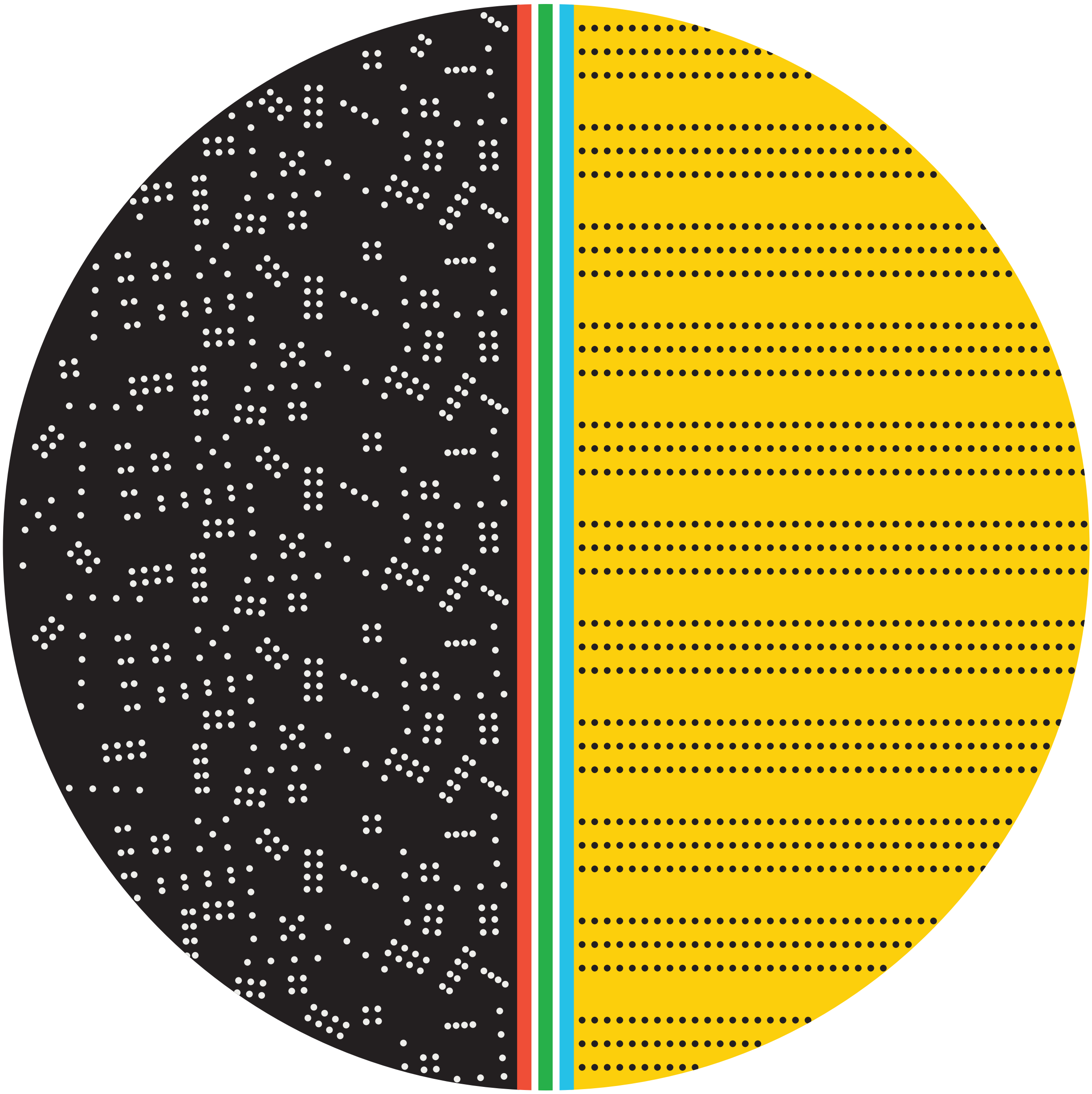

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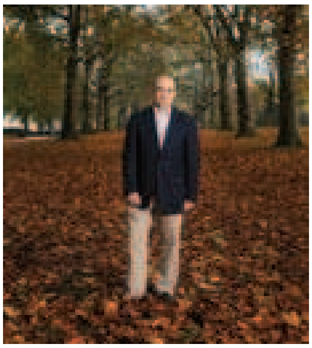

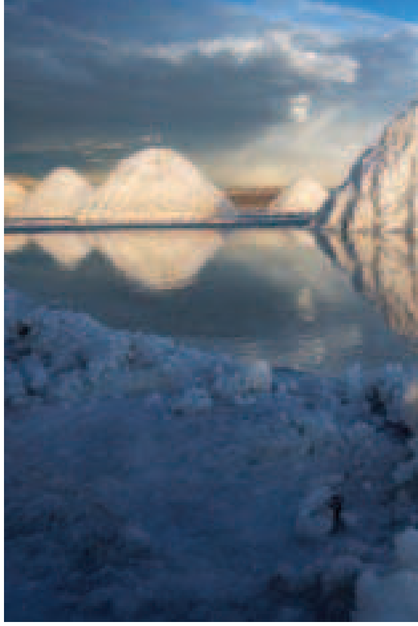


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303-975-6381

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415-659-2982

New York and Northeast
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857-998-9241

New England, Detroit, and Canada
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barry.echavarria@technologyreview.com
603-924-7586

Mid-Atlantic and Southeast
Clive Bullard
cbullards@cs.com
845-231-0846

Northwest
Steve Thompson
stevet@mediacentricinc.com
415-435-4678

Europe
Anthony Fitzgerald
mail@afitzgerald.co.uk
44-1488-680623

France
Philippe Marquezy
philippe.marquezy@espacequadri.com
33-1-4270-0008

Germany
Michael Hanke
michael.hanke@heise.de
49-511-5352-167

China
RP Soong
rpsoong@mittrchinese.com
010-8280-9083

India
Aninda Sen
anindas@cybermedia.co.in
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Japan
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TECHNOLOGY REVIEW, INC., identifies emerging technologies and analyzes their impact for technology leaders. Technology Review publishes *Technology Review* magazine (the oldest technology magazine in the world, founded in 1899) and the daily website TechnologyReview.com; it also produces live events such as the EmTech Conference. Technology Review is an independent media company owned by the Massachusetts Institute of Technology. The views expressed in our various publications and at our events are often not shared by MIT.

BRYANT URSTADT examines the fast-paced automated trading of stock, a growing trend that critics say is making the financial system more unstable (*"Trading Shares in Milliseconds," p. 44*). "I first got interested in high-frequency trading in the summer of 2008," says Urstadt. "Funds were collapsing, banks were teetering, and stocks were in an endless nosedive, but there was one odd exception: secretive funds, all traded entirely by algorithms, were going in the opposite direction, making absolutely huge returns. Some were even having their best year ever. No one seemed to know how they were able to go so far up when everyone else was crashing. That Manoj Narang so graciously explained exactly how funds like his worked was the kind of luck a writer wakes up every morning hoping for." Urstadt is a regular writer for *Harper's*. He has previously written for *TR*, *New York*, and *Outside*.

JEFF FOUST reviews the debate over the benefits of human spaceflight (*"The Future of Human Spaceflight," p. 75*). "We're at a crossroads," he says. "In about a year, the space shuttle will be retired, and we'll have several years where we will not be able to launch humans into space. This raises a question: why spend billions of taxpayer dollars a year on human spaceflight at all? A lot of the rationales that have been used in the past—science, technology spinoffs, international prestige—don't seem sufficient today. A panel commissioned

by the White House decided that the ultimate goal for human spaceflight should be to allow for eventual human expansion into the solar system. With this goal, steps NASA should take become clear: for example, supporting the development of commercial systems to do routine tasks." Foust is a senior analyst and project manager with Futron in Bethesda, MD, where he studies trends for domestic and foreign commercial, civil, and military launch industries. He is the editor and publisher of the *Space Review* and maintains the space news aggregator Spacetoday.net and the policy blog Space Politics.

ANTONIO REGALADO writes this issue's photo essay on Bolivia's vast, untapped deposit of lithium, the key ingredient in the batteries that power electric vehicles (*"The Lithium Rush," p. 26*). "Bolivia has a populist socialist government along the lines of Hugo Chavez's Venezuela, in which domination of information flow is a major goal of the government," says Regalado. "The government sees itself as the true representative of a suppressed indigenous population. We will see whether their rhetoric about seizing the country's resources for the state achieves syncretism with the capitalist models of investment most capable of extracting those resources, including lithium." Regalado is a freelance reporter living in São Paulo, where he writes about slum music, armored cars, and other local phenomena. Previously, he was a science reporter at the *Wall Street Journal* and an editor at *Technology Review* covering biomedicine.

NOAH FRIEDMAN-RUDOVSKY is a freelance photojournalist who shot the photo essay. "On the salt flats, you find yourself in a sea of pure white that extends to the horizon," he says. "Workers at the lithium pilot plant work 20-day shifts at this remote spot, wearing ski masks, sunglasses, and overalls, covering every inch of their skin from the sun. They seem connected to the ambitious project that hopes to convert the lithium deposit into social ben-

efits for Bolivia's poor." Friedman-Rudovsky photographs stories in Bolivia and across Latin America. His coverage appears regularly in the *New York Times*, and his photos have been published in the *New Yorker*, *Der Spiegel*, *Paris Match*, and the *New York Times Magazine*.

THE FATHER OF SHALE GAS

Our cover story on the vast amounts of natural gas trapped in shale deposits in the northeastern United States ("Natural Gas Changes the Energy Map," November/December 2009) prompted one reader to write in about the person who pioneered the techniques that now make extracting that gas economically viable.

David Rotman's article was informative and thoughtful but had one glaring deficiency. There is just a single line referring to the fact that the crucial drilling techniques were developed in Texas, but the vast gas reserves in the Northeast are accessible thanks entirely to 17 years of drilling experimentation led by George Mitchell and his company, Mitchell Energy and Development. Mitchell didn't put the gas there, but he showed how to get it out. Leaving his name out of the article is like having an article on the theory of relativity that leaves out the name Einstein and instead briefly mentions some contributions made in the Swiss Patent Office.

William H. Bassichis
College Station, TX

November/December '09

HUMAN NEEDS, TECHNOLOGICAL SOLUTIONS

Editor in chief Jason Pontin's letter "Ghosts in the Machine" (November/December 2009) detailed the personal experiences that prompted him to have chief correspondent David Talbot take a look at the way electronic health records can be used to help poor and underserved patients in American hospitals ("Prescription: Networking").

I was touched by Jason Pontin's editorial on many levels, not least by his willingness to share what is such a poignant part of his past. David Talbot's article describing a network that links the records at a major Boston hospital to those at 10 community health centers is excellent, and I shall forward it to all my informatics students here at Johns Hopkins University School of Medicine. The poignancy of both articles is that we are still relying on anecdotes to motivate these types of technological solutions. It is a sad state of affairs that we recurrently decry the lack of a business case for interoperability—and that we must rely on business cases in the first place rather than cater to these really crucial human needs.

Harold P. Lehmann, MD
Baltimore, MD

A doctor in the field argues that the solutions described in the article are still insufficient.

While electronic health records offer great promise in recording and distributing objective patient data, their ability to handle subjective data has been less impressive. This is a crucial failing and, in my opinion, the reason doctors have not enthusiastically embraced them. The interaction between doctor and patient, even in this technological era, remains of paramount importance. It is difficult to digitize, and the onerous data entry involved in most EHR systems steals time from doctors that could otherwise be used at the bedside. Physicians who object are often dismissed as Luddites resisting change. Until their complaints are addressed, physicians will continue to have reservations about adopting EHRs, despite their potential benefits. Give us a tool that works and we will use it.

Frank Venuti, MD
Big Flats, NY

NUCLEAR RISKS

Matthew Wald's article on the 30th anniversary of Three Mile Island ("Nuclear Power Renaissance?" November/December 2009) discussed three risk factors currently facing the nuclear industry: the cost of building a new reactor, uncertainty about future competitors, and uncertainty about the price of fossil fuels. A commenter online suggested another.

There is a fourth risk factor that I believe holds equal weight: regulatory uncertainty and inflexibility. The new one-step reactor licensing process is still untested, and until one or two new units go through the process, the investment community will be jumpy. Also, while several companies and groups are promoting small reactors that would lower the cost of entry and enable investors to scale nuclear capacity gradually, the Nuclear Regulatory Commission appears reluctant to devote sufficient resources to reviewing the designs. Small-reactor vendors are in a catch-22: the NRC says it won't devote resources until the companies have customers, yet customers are unlikely to sign up without a certified design. As a result, we're likely to see American ingenuity and investment heading overseas to build small reactors in a more friendly and stable regulatory climate.

John Wheeler
Zionsville, IN

CORRECTIONS: The image on page 32 of the November/December 2009 photo essay should have been credited to Maria Carmen Piñon and Zoltán Molnár, University of Oxford.

A map on page 66 in the November/December 2009 Briefing on transportation, showing high-speed rail lines worldwide, neglected to show the Taiwan High Speed Rail line, which began service in January 2007.

An article in the September/October 2009 Briefing on electricity incorrectly stated that peak demand for New York City is 35,000 megawatts. That is the peak demand for the entire state of New York.

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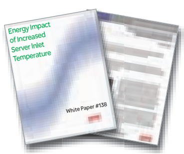

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MARK OSTOW

On the Evolution of Technology

NEW TECHNOLOGIES ARE MISSING MANY THINGS, BUT ESPECIALLY THEIR MARKETS.

When a technology first appears in the world, it is not understood: no one knows what to do with it.

In a review of the Biomark 96.96 Dynamic Array, a microfluidic chip made by Fluidigm, a startup in South San Francisco *(see "Shoveling Water," p. 70)*, David Rotman, *Technology Review's* editor, asks why such chips are not more widely used. The Fluidigm chip, which (considered purely as an artifact) is a very beautiful thing, "represents a decade of successive inventions," Rotman writes, and such chips, in general, are "a fundamental breakthrough in how researchers can interact with the biological world." Microfluidic chips "allow biologists and chemists to manipulate tiny amounts of fluid in a precise and highly automated way." And yet these chips, which bear some resemblance to an electronic microprocessor, "with valves replacing transistors and channels replacing wires," will not live up to the comparison to microelectronics until they have made the transition "from promising laboratory tool to widely used commercial technology." Possible applications include a variety of diagnostic uses, but the technology still lacks what the software industry calls the "killer app."

Rotman reviews the chip *and* Brian Arthur's book *The Nature of Technology: What It Is and How It Evolves*, and like many contributors to our Reviews section, he uses the occasion to make a broader point about technology. Arthur, a former professor of economics and population studies at Stanford, wishes to propose a grand theory of technology, akin to the one for science that Thomas Kuhn set out in *The Structure of Scientific Revolutions.* What interests Rotman is Arthur's explanation of why truly new technologies, like microfluidic chips, are so slow to be adopted.

Arthur makes a distinction between bodies of technology, or "domains," such as electronics, photonics, and microfluidics, and their individual technologies. Domains emerge "piece by piece." Technologies within domains may be adopted quickly, but only after those domains have been encountered first by users who are bewildered. What are these technologies? How are they used? What do they allow people to do that could not be done before, or at least not as efficiently? Always, new domains betray "missing pieces" that technologists must develop before useful applications can be successfully commercialized. All this, says Arthur, "normally takes decades. It is a very, very slow process."

Arthur's observation is consistent with a general principle sometimes called "Cringely's Law," after the pundit Robert X. Cringely, who proposed it. Cringely's Law states that short-term adoption of new technologies never occurs as quickly as we expect, but their long-term impact is far greater than we realize.

One market-oriented way of thinking about the protracted adoption of new technologies is to understand that among the "missing pieces" of new domains are the modes of business that will sustain the constituent technologies. That is to say: the real economic value of new technologies is almost always imperfectly understood because the technologies' markets do not yet exist.

At *Red Herring*, a magazine I edited during the dot-com boom, we were so conscious of this phenomenon we had a name for its effect: "the Rule of the Second-Mover Advantage." (I last wrote about it in "The Rules of Innovation," May 2005, and at technologyreview.com.) We meant that the first attempt to commercialize a technology almost never succeeds, but another organization will succeed where the original innovator failed. IBM, for example, first commercialized the personal computer, but Microsoft controlled the "platform" for its software and therefore benefited most. The best recent example, however, is in search. There were many search engines before Google—some of them, like AltaVista, possessing technology the equal of PageRank, Google's algorithm for ranking the popularity of Web pages. But Google was first to see that the monetary value of search was in keyword advertising; that "missing bit" created the link economy and overturned media *(see Briefing, p. 59)*.

What will be the markets for microfluidics? Rotman offers a few guesses. Drug companies might use microfluidics to show how genes are expressed in cells: "In one experiment, cancer researchers are using one of Fluidigm's chips to analyze prostate tumor cells, seeking patterns that would help them select the drugs that will most effectively combat the tumor." Microfluidics could also make possible cheap, portable diagnostic devices for the poor and developing world, where treatable diseases often go undiagnosed *(see "TR 10: Paper Diagnostics," March/April 2009)*.

The modes of business that sustain a new technology influence its further development. Norbert Wiener, the founder of cybernetics, showed that this influence is self-amplifying and, eventually, destabilizing. To commercialize a technology is to sow the seeds of its dissolution. IBM's mainframes were succeeded by Microsoft's software, which has been succeeded by Google's keywords, which will be succeeded by something else. Nothing lasts forever, or even for very long. But write and tell me what you think at jason.pontin@technologyreview.com.

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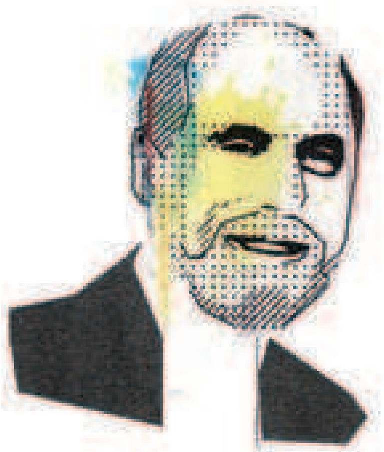
Expert opinion



COMPUTING

Integrating the Clouds

THE NEXT STEP IN CLOUD COMPUTING IS TO LINK DIFFERENT SYSTEMS, SAYS VINTON CERF.

At Google, we operate many data centers around the world, each of which contains a large number of computers linked to one another in clusters. In turn, the data centers are linked through a high-speed private network. These data centers support applications and services that users can access over the public Internet to tap into virtually unlimited computing power on demand, a process known as cloud computing *(see "Security in the Ether," p. 36)*. Amazon, IBM, Microsoft, and others are implementing and experimenting with similar systems. Currently, these clouds operate in isolation, communicating only with users. But I think we need to start developing interfaces so that clouds can communicate directly among themselves.

An integrated cloud would have a number of advantages. Users may wish to move data from one cloud to another without having to download all their data and then upload it again. Or users may want to store the same data in multiple clouds for backup. In this case, reliable mechanisms for synchronizing data across different clouds would be useful. Some may wish to do coördinated computation in multiple clouds.

How can a program running in one cloud reference data in another? If one cloud puts restrictions on access to data, how can those controls be replicated in a second cloud? What protocols, data structures, and formats will allow clouds to interact at users' direction and in accordance with their requirements?

Researchers are investigating these and other questions, with limited success so far. One approach that intrigues me reaches back into the pre-Internet days of the ARPAnet. The different operating systems of the day used many different kinds of remote terminals and text encoding schemes. ARPAnet researchers concluded that the most effective way to support remote access between interlinked time-shared computers was to define a "network virtual terminal" (NVT). The NVT did not physically exist anywhere, but all operating systems were equipped to translate between the NVT format and their native modes of terminal operation. One might imagine a similar idea for cloud computing: define a network virtual cloud with a set of functional characteristics intended to be generally realizable by all cloud providers. Interactions among clouds would appear to be happening through an intermediate virtual cloud. In this model, each cloud could translate its internal method of organizing data to and from standardized naming conventions, data exchange protocols, and perhaps data description protocols. It is too early to tell whether such proposals will gain traction, but these and other ideas will need to be explored if we are to make the most of cloud computing. TR

VINTON CERF IS VICE PRESIDENT AND CHIEF INTERNET EVANGELIST AT GOOGLE. IN THE 1970S AND '80S HE WORKED AT DARPA, WHERE HE IS WIDELY CREDITED WITH DEVELOPING THE INTERNET.

ENVIRONMENT

Why Geoengineering?

M. GRANGER MORGAN EXPLAINS WHY WE MUST STUDY THE CONSEQUENCES OF SHADING THE EARTH.

Scientists already know how to cool the planet quickly. The secret is geoengineering: specifically, using very fine particles in the stratosphere to reflect sunlight *(see "The Geoengineering Gambit," p. 50)*. The direct cost of shading the planet this way could be less than a few hundredths the cost of reducing carbon dioxide emissions. If reflecting sunlight is fast and cheap, why struggle with all the problems of collective action to achieve emission reductions? Why not

PADDY MILLS

wait until we have a climate problem and then simply fix it?

Over the past half-century, people have "fixed" a number of other problems with environmental implications. We have reversed rivers in Russia, inadvertently destroying the Aral Sea in the process; we have built roads and encouraged farming in tropical areas, inadvertently depleting the soil and destroying millions of acres of rain forest. If, with typical shortsightedness and hubris, we count on geoengineering to save the planet, can we be sure that the outcome will be what we intend?

Despite the mistakes of the past, the answer is not to treat geoengineering like chemical and biological weapons research, surrounding it with a global taboo. If a country experiencing a prolonged drought, for example, seeks to engineer the planet's climate unilaterally, we will need to be familiar with the potential consequences in order to muster informed counterarguments. And if our more extreme climate-change predictions become reality and a sudden climate emergency puts billions of people at risk, the world should not find itself collectively embarking on a crash program of geoengineering in ignorance.

We need to know much more about geoengineering. Until recently, most scientists and research managers have been reluctant to do research in this area, for fear that knowing how to engineer the climate would encourage people to do it. But today, the risks of avoiding research outweigh the risks of pursuing it.

We need to take two steps now. First, we should establish a loosely coördinated international program aimed at researching how to shade the planet, how much it would cost, and what the intended and unintended effects would be. This research should also address what the rising atmospheric concentration of carbon dioxide means for terrestrial and oceanic ecosystems, since reflecting sunlight will do nothing to stop it. About one third of emitted carbon dioxide is absorbed by the oceans, which become more acidic as a result; they are already 30 percent more acidic today than they were in preindustrial times. If current emissions continue, most coral reefs could be gone by the end of the century, along with all the ecosystems they support.

Second, we need to get the foreign-policy community working on a collective approach to regulating geoengineering. My colleagues and I have started that process with two international workshops involving climate scientists and foreign-policy experts. Further informal discourse will lay the groundwork for a formal framework. TR

M. GRANGER MORGAN IS HEAD OF THE DEPARTMENT OF ENGINEERING AND PUBLIC POLICY AT CARNEGIE MELLON UNIVERSITY.

MEDIA

The New News

JAY ROSEN PULLS APART JOURNALISM AND THE MEDIA.

Journalism, the practice, is not "the media," although for many years most of the journalism that got done was done inside the media industry. Now that industry is in trouble, but not because people no longer want to be informed or entertained (they still do). Rather, the social pattern that sustained the media industry has been disrupted by technology *(see Briefing, p. 59)*.

The media used to work in a one-to-many pattern—that is, by broadcasting. The Internet, though it *can* be used for one-to-many transmission, is just as well suited for few-to-few, one-to-one, and many-to-many patterns. Traditionally, the media connected audiences "up" to centers of power, people of influence, and national spectacles. The Internet does all that, but it is equally good at connecting us laterally—to peers, to colleagues, and to strangers who share our interests. When experts and power players had something to communicate to the attentive publics they wished to address, they once had to go through the media. Now they can go direct.

Because for a long time the media industry was relatively stable and was the setting in which journalism was practiced, we got into the habit of calling journalism the "news media," and then just "the media." Journalism and the system that carries it became equated.

In the 1970s and '80s, a number of classics in press scholarship were written by social scientists who went into newsrooms to study how decisions were made. They all observed that "routines" drive what happens in journalism, and that these routines ultimately served the demands of a particular production cycle: the daily newspaper, the 6 P.M. broadcast, the monthly magazine.

Ideas about what journalism is—and even what it can be—get trapped within these routines as they become second nature. What happens when the production routine shifts radically, as with the Web, and news producers confront a different social pattern? Journalists insist that their habitual practices are not artifacts of a technological era but the essence of good journalism. They shouldn't do that, and they wouldn't, if they understood what I said at the start: journalism is not the media. TR

JAY ROSEN TEACHES JOURNALISM AT NEW YORK UNIVERSITY.

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Source: reader.intel.com
Company: Intel

Take a snapshot of this code to read a special report on smarter IT. For the software, visit www.neoreader.com.

JOSHUA SCOTT

GEEK GIFTS

For this year's holiday season, here are some offbeat items that caught the eye of the editors of *Technology Review*.

DIY CSI

EXTRACTING your own DNA with this kit is interesting enough, but it also lets you mix up a bottle of ink incorporating your genetic material, for the ultimate in forgery-proof signatures.

Product: ScienceWiz 123 DNA Extraction
Cost: $15 **Availability:** Now
Source: sciencewiz.com
Company: Norman and Globus

TOUGH PHONE

BUILT TO military standards, the Rock phone can survive being dropped, shocked, drowned, and baked to 85 °C. It also features a pedometer, thermometer, tide calculator, and GPS.

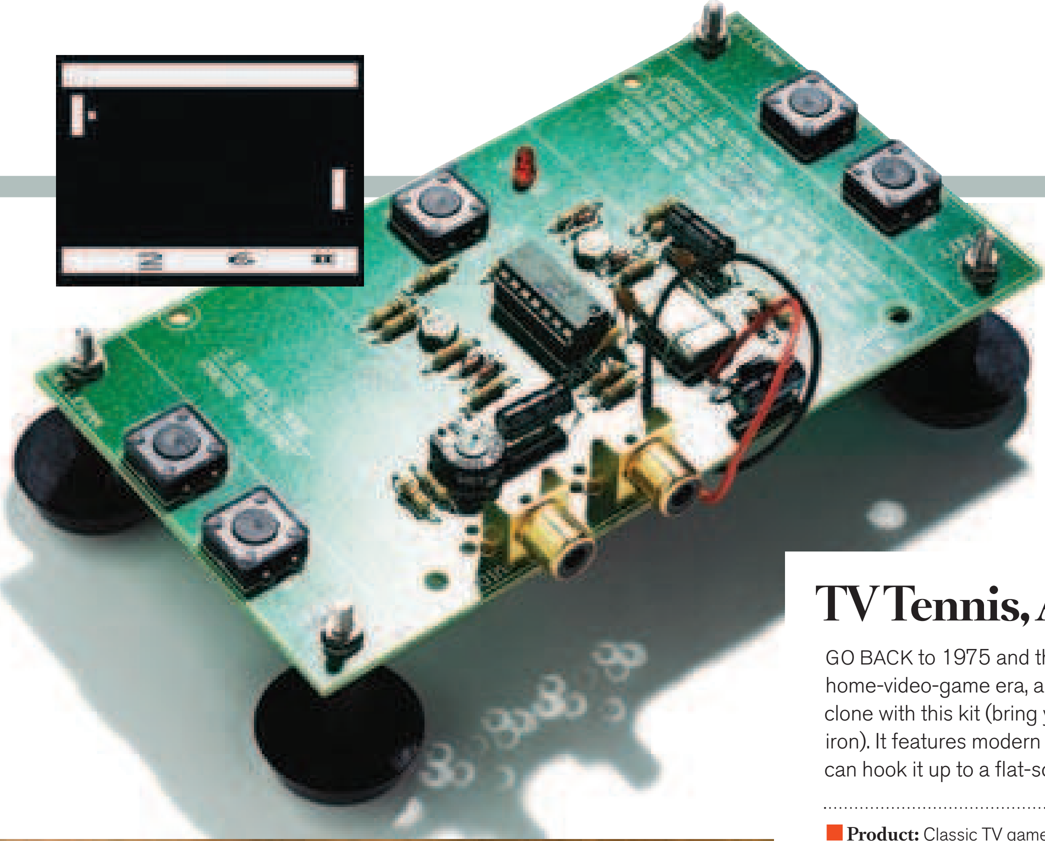
Product: G'zOne Rock phone
Cost: $200 with contract **Availability:** Now **Source:** www.casiogzone.com
Companies: Casio, Verizon

GO HOME TO ROVIO

YOU CAN control the Rovio robot over the Web or set it to patrol your home autonomously. Video from the robot's camera can be relayed anywhere in the world, and you can even carry on a two-way conversation with anyone near the robot, using its built-in speaker and microphone.

Product: Rovio **Cost:** $230 **Availability:** Now
Source: wowwee.com **Company:** WowWee

JOSHUA SCOTT; COURTESY OF WOWWEE (ROVIO)



TV Tennis, Anyone?

GO BACK to 1975 and the dawn of the home-video-game era, and build a Pong clone with this kit (bring your own soldering iron). It features modern A/V outputs so you can hook it up to a flat-screen TV.

Product: Classic TV game **Cost:** $21.80 **Availability:** Now **Source:** vellemanusa.com **Company:** Velleman

JOSHUA SCOTT

CHEMICAL RECIPES

ADD A DASH of scientific sizzle to your kitchen with a molecular-gastronomy kit. The kit contains specialized tools, including pipettes and silicone tubing, and ingredients (like agar and carrageenan) that can be used to create six unusual desserts, including red fruit juice caviar and sparkling soft toffees. A booklet explains the chemistry behind each recipe.

Product: Molecular-gastronomy starter kit **Cost:** $60 **Availability:** Now **Source:** cuisine-innovation.com **Company:** Cuisine Innovation

SMART GRID

KEEPING AN EYE ON ELECTRICITY

MILLIONS of dollars are being spent to install smart meters that alert utility customers to the minute-by-minute price of the electricity they are using at home. The hope is that consumers will adjust their use of power according to its cost. But this assumes they remember to check the meter before pressing an "on" button. The edot is a smart-meter display that can be stuck directly onto most appliances with a built-in magnet. It communicates wirelessly with the smart meter, and its ultra-low-power radio link means that consumers never change its batteries; each edot will last between five and seven years.

Product: Edot in-home energy display **Cost:** Approximately $10 in high volume **Availability:** Now **Source:** taloncom.com/smartenergy **Companies:** Talon Communications, Texas Instruments

LAPTOPS

Making 3-D Pop

3-D COMPUTER GAMING has been underwhelming to date, largely because awkward add-on hardware is typically required to support 3-D glasses, and because frame rates are relatively low. (A 3-D system needs to generate twice as many images per second as a standard screen to perform equivalently in gaming applications.) The G51J solves these problems by using built-in graphics hardware that operates LCD shutter glasses at 120 hertz. That's 60 frames per second for each eye, fast enough for all but the most hard-core gamers. Most modern titles do not have to be redesigned to be played in 3-D.

Product: G51J 3D laptop **Cost:** $1,700 **Availability:** Now **Source:** www.asus..com **Companies:** Asus, Nvidia

JOSHUA SCOTT; COURTESY OF ASUS (NOTEBOOK)

What's the fastest way to learn a language?

ACT LIKE A BABY.

It's not the advice you'd expect. Learning a new language seems formidable, as we recall from years of combat with grammar and translations in school. Yet infants begin at birth. They communicate at eighteen months and speak the language fluently before they go to school. And they never battle translations or grammar explanations along the way.

Born into a veritable language jamboree, children figure out language purely from the sounds, objects and interactions around them.

Their senses fire up neural circuits that send the stimuli to different language areas in the brain. Meanings fuse to words. Words string into structures. And language erupts.

Three characteristics of the child's language-learning process are crucial for success:

First, and most importantly, a child's natural language-learning ability emerges only in a speech-soaked, immersion environment free of translations and explanations of grammar.

Second, a child's language learning is dramatically accelerated by constant feedback from family and friends. Positive correction and persistent reinforcement nurture the child's language and language skills into full communicative expression.

Third, children learn through play, whether it's the arm-waving balancing act that announces their first step or the spluttering preamble to their first words. All the conversational chatter skittering through young children's play with parents and playmates—"…what's this…" "…clap, clap your hands…" "…my ball…"—helps children develop language skills that connect them to the world.

Adults possess this same powerful language-learning ability that orchestrated our language success as children. Sadly, our clashes with vocabulary drills and grammar explanations force us to conclude it's hopeless. We simply don't have "the language learning gene."

At Rosetta Stone,® we know otherwise. You can recover your native language-learning ability as an adult by prompting your brain to learn language the way it's wired to learn language: by complete immersion. Our award-winning, computer-based method does just that.

Dynamic Immersion® unlocks the innate language-learning ability you acquired before birth and mastered as a child.

By recreating the immersion context in which you learned your first language, you understand, speak, read and write your new language with confidence and accuracy from the beginning—without translations and explanations.

At every step and in every skill, you receive instant, actionable feedback, including speech recognition and analysis technologies that prepare you for everyday conversations. And Adaptive Recall® brings back material just when you need it to reinforce and perfect your learning.

Every act of learning is an act of play for children and there's no reason it should be different for learners of any age. With Rosetta Stone programs, you rediscover the joy of learning language. Clever, puzzle-like activities produce sudden "Aha!" moments and astonishing language discoveries.

Your "language brain" remembers. We see it all the time.

A slow smile sneaks across the learner's face after just a few screens. It's a smile of recognition, as though the brain suddenly recalls what it was like to learn language as a child, as though it realizes, "Aha! I've done this before."

Act like a baby? You bet. Visit our website and find out how you can reactivate your own innate, language-learning ability with Rosetta Stone. It's the fastest way to learn a language. Guaranteed.®

More than 30 languages available.

SAVE 10%

Level 1	$206
Level 1&2	$368
Level 1,2&3	$485

SIX-MONTH, NO-RISK MONEY-BACK GUARANTEE.*

PICK UP A NEW LANGUAGE TODAY!
(866) 877-9535 RosettaStone.com/rvs010
Use promo code rvs010 when ordering.

RosettaStone®

WIRELESS

USB OVER THE AIR

A FEW years ago, it looked as if wireless USB technology would soon make the data cables that snake around our desks as obsolete as cathode-ray-tube monitors and floppy disks. But that turned out to be a false start. Now, the first wireless USB hard drive is finally on the market, boasting a capacity of 1.5 terabytes and a data transfer rate of up to 15 megabytes per second.

Product: Pro WX wireless USB hard drive **Cost:** $450 **Availability:** Now **Source:** imation.com **Company:** Imation

MEMORY

MORE BITS FOR THE BUCK

X4 FLASH MEMORY chips can store four bits per memory cell instead of the two bits per cell of conventional chips. Thanks to the extra bits, a memory card of any given capacity should be 20 to 30 percent less expensive.

Products: X4 Flash Memory
Cost: $10 to $200, depending on capacity and retailer pricing
Availability: Now
Source: sandisk.com
Company: SanDisk

PHOTOVOLTAICS

Get a Charge on the Go

THIS BACKPACK is one of a line of sports bags and packs that incorporate flexible solar cells to charge mobile devices. These are the first commercial products to use dye-sensitized thin-film solar cells, which have a lower efficiency than traditional photovoltaic cells—about 12 percent—but offer several important benefits. They're cheap to produce, they can be printed on flexible materials, and they can work well with indoor lighting sources such as fluorescent bulbs.

Product: Solar bags powered by G24 **Cost:** N/A **Availability:** Early this year **Source:** www.mascotte.com **Companies:** Mascotte Industrial Associates, G24 Innovations

JOSHUA SCOTT; COURTESY OF MASCOTTE (BAG)

Q&A

MIKE LYNCH

Nicole Kidman is not a cosmic gas ball.

Michael Lynch, the cofounder and chief executive of Autonomy, built Britain's largest software company by solving a hard problem in computer science: how do you find something obscure within unstructured data—that is, within information not organized into fields that are recognized by databases (whether text, audio, or video), which constitutes most of what has ever been digitally recorded? Autonomy's technology (which is licensed by diverse organizations) supplements traditional search methods with pattern recognition techniques derived from Bayesian inference, an abstruse form of statistical analysis. He spoke with *TR*'s editor in chief, Jason Pontin.

_TR:_ Why do I care about unstructured information?

Lynch: Because we are human beings, and unstructured information is at the core of everything we do. Most business is done using this kind of human-friendly information. About 85 percent of the information inside a business is unstructured.

Why is searching unstructured information such a problem?

With structured information, you can simply ask, Does A equal B? With unstructured information, you have a more complex situation. You have the concept of ideas not matching but having nearness to each other: in one sense "dog" doesn't equal "Labrador," but in another sense it does. It's a *very* difficult area for computers to understand.

Why not use Boolean logic [which search engines use to interpret keyword queries]?

In order to construct a Boolean query, you have to be quite skilled—and you have to know what you're looking for. Let's say that we wanted a computer to spot all articles about Apple. We could look for the ticker symbol. But there would be lots of articles about Apple without that. So we might have "Apple + computer" or "Mac + computer" and "*not* apple + tree" and "*not* apple + fruit," etc. Pretty soon, we'd end up with a very complex expression. But the real problem is that as we create this kind of construction, the world changes—and suddenly we have to edit our complex expression and put "iPhone" in it.

Why can Bayesian inference, with its foundation in probability, search unstructured data better?

There have been two attempts to create systems that can learn how ideas relate to each other without those ideas having to be predefined. The first is very intuitive: it uses semantic methods. The computer understands the rules of grammar, and it sort of analyzes things. But there's a fundamental problem. If I said to you, "The dog walked into the room and it was furry," you can define the "it." But you have some knowledge. You know that, statistically, dogs are more likely to be furry than rooms. So the people who work on these problems get into situations where they have PhDs sitting in back rooms defining that dogs have the property of furriness. And that starts to fall apart because the relationships between ideas are not absolute; they're conditional. Now, the other approach—which we use—is counterintuitive: you treat the whole thing as a mathematical problem.

How so?

Imagine that you took all the newspapers and books, and you cut out all the words, and put them in a black bag: you would have a random process. You would expect nothing but gobbledygook. But if we pick a real page of text, it's not random: if we read the word "dog," then the probability that you will see the word "walk" increases. The reason is that the process has been biased by something: the idea of the dog that was in the mind of the author of the sentence. By using Bayesian inference, you can, in fact, infer the existence of the idea behind the word and all its relationships. The wonderful thing is you inherently get context. With Bayesian systems, you understand that just because Nicole Kidman is a star doesn't mean she's a cosmic gas ball.

Why can't Google's algorithms search unstructured information?

Just because you've been very good at keyword-based, popularity-ranked search doesn't actually buy you much advantage processing unstructured information where you have to understand meaning.

You have philosophical as well as practical objections to the curatorial approach to search embraced by Wolfram Alpha *(see "Search Me," July/August 2009 and at technologyreview.com).*

Those methods can work very well in limited contexts. But there are some big philosophical problems with the idea that information is absolute in meaning and that you can classify it just one way. If you come from the probabilistic world, the first thing you learn is that you have to deal with people's worldviews. A very simple example: a computer might classify the same news story differently if it was working for a Palestinian newspaper or an Israeli one. But there's nothing wrong with that. This notion that all information should have the same meaning is something that we've been taught by the idea of objective science since the Reformation. But for lots of the tasks that people need to do, it's perfectly acceptable that meaning should be in the eye of the beholder. TR

Photograph by JUDE EDGINTON

The 10,000-square-kilometer Uyuni salt flat (*salar* in Spanish) extends to the horizon in all directions. These days it's a breeding ground for pink flamingos and a draw for curious tourists, but in prehistoric times it was once an immense lake. Water falling in the Andes still flows here, and as it works its way over volcanic rocks toward the *salar*, it picks up minerals, including magnesium and lithium. Baked by the sun, the water becomes a mineral-rich brine that flows under the salt desert's crusty surface.

PHOTO ESSAY

The Lithium Rush

Nearly four kilometers above sea level in the Bolivian Andes lies the Salar de Uyuni, the world's largest salt flat. But there is more to this surreal, moonlike landscape than meets the eye. Flowing in salt-water channels beneath the surface is the world's largest supply of lithium—and, possibly, the future of transportation. Lithium is the key ingredient in the lithium-ion batteries that will power the electric vehicles that will soon be rolling off production lines worldwide. Demand for the metal is expected to double in the next 10 years, and Bolivia, with an untapped resource estimated at nine million tons by the U.S. Geological Survey, is being called a potential "Saudi Arabia of lithium."

By ANTONIO REGALADO *Photographs by* NOAH FRIEDMAN-RUDOVSKY

Although the lithium here could be worth billions, the Bolivian government is just beginning to exploit the vast resource. At far left, workers operate a perforation drill to probe for brine up to 50 meters beneath the surface. Where lithium concentrations are highest, the brine is pumped into evaporation pools (below). The sun evaporates water at an average rate of seven millimeters a day on the *salar*, gradually concentrating the lithium. Transferring the brine through a series of pools will concentrate it further and eliminate some impurities, a process that takes more than a year.

Here, local politicians and members of the public get a tour of the site. Patriotic passions are running high in Bolivia, where companies from Europe and Asia have arrived in hopes of extracting Uyuni's lithium. So far, negotiations are deadlocked, and President Evo Morales warns that he won't let companies "pillage" his country's resources the way Spanish conquistadors once carried off silver from its mines. Although Bolivia needs foreign expertise and investment to fully exploit the lithium, Morales insists that his government must stay in control. "That's not a very attractive business model for a Western company," says Eric Norris, commercial director of FMC Lithium, which produces lithium in Argentina.


COMIBOL
AREA DE TRABAJO

A pilot facility is under construction at the edge of the salt flat, where technicians use buckets to measure evaporation rates. Overhead fly the Bolivian flag (at left) and the Wiphala flag representing indigenous rights, a major concern of Bolivia's socialist government. Because Bolivia's technical infrastructure is limited, many brine samples have been sent to South Korea, France, and Japan for analysis. Brine tested so far has high levels of impurities such as magnesium and borate, which researchers will have to find ways to remove. Eventually, Bolivia's government hopes to build a full-scale industrial plant near the flat, where lithium brine will be mixed with lime and soda ash to produce lithium carbonate, the fine white powder that's a key ingredient in lithium-ion batteries. Above, at a laboratory in La Paz, a technician holds a sample of pure lithium carbonate.

Until very recently, industry on the flat was limited to harvesting the salt on its surface—like the piles of ordinary table salt that local workers are loading in trucks to haul away, below. But with batteries expected to eat up 40 percent of the world's lithium output by 2020, this remote region is now a focus of intense global interest. "If we don't get lithium from this place, we cannot produce our cars," says Oji Baba, a Japanese executive with Mitsubishi. In the U.S., anticipation is high for the forthcoming Chevy Volt, which will run for 40 miles on battery power alone. But will the Volt ever run on Bolivian lithium? "For the next five years, automotive won't make a dent in lithium supplies," says Mark Verbrugge, director of the Chemical Sciences and Materials Systems Laboratory at GM. After that, it's anyone's guess. What's certain, says Verbrugge, is that the percentage of vehicles eventually powered by batteries "could be enormous."

WWW See more photos of the Uyuni salt flat: **technologyreview.com/lithium**

Security in the Ether

Information technology's next grand challenge will be to secure the cloud—and prove we can trust it.

By DAVID TALBOT

In 2006, when Amazon introduced the Elastic Compute Cloud (EC2), it was a watershed event in the quest to transform computing into a ubiquitous utility, like electricity. Suddenly, anyone could scroll through an online menu, whip out a credit card, and hire as much computational horsepower as necessary, paying for it at a fixed rate: initially, 10 cents per hour to use Linux (and, starting in 2008, 12.5 cents per hour to use Windows). Those systems would run on "virtual machines" that could be created and configured in an instant, disappearing just as fast when no longer needed. As their needs grew, clients could simply put more quarters into the meters. Amazon would take care of hassles like maintaining the data center and network. The virtual machines would, of course, run inside real ones: the thousands of humming, blinking servers clustered in Amazon's data centers around the world. The cloud computing service was efficient, cheap, and equally accessible to individuals, companies, research labs, and government agencies.

But it also posed a potential threat. EC2 brought to the masses something once confined mainly to corporate IT systems: engineering in which Oz-like programs called hypervisors create and control virtual processors, networks, and disk drives, many of which may operate on the same physical servers. Computer security researchers had previously shown that when two programs are running simultaneously on the same operating system, an attacker can steal data by using an eavesdropping pro-

JASON MADARA

CLOUD CROWD
Some 4,000 servers hum at IBM's cloud computing center in San Jose, CA.

"If you don't have everybody using the cloud, you can't have a cheap service. But when you have everybody using the clouds, you have all these security issues that you have to solve suddenly."

gram to analyze the way those programs share memory space. They posited that the same kinds of attacks might also work in clouds when different virtual machines run on the same server.

In the immensity of a cloud setting, the possibility that a hacker could even find the intended prey on a specific server seemed remote. This year, however, three computer scientists at the University of California, San Diego, and one at MIT went ahead and did it *(see "Snooping Inside Amazon's Cloud," p. 39)*. They hired some virtual machines to serve as targets and others to serve as attackers—and tried to get both groups hosted on the same servers at Amazon's data centers. In the end, they succeeded in placing malicious virtual machines on the same servers as targets 40 percent of the time, all for a few dollars. While they didn't actually steal data, the researchers said that such theft was theoretically possible. And they demonstrated how the very advantages of cloud computing—ease of access, affordability, centralization, and flexibility—could give rise to new kinds of insecurity. Amazon stressed that nobody has successfully attacked EC2 in this manner and that the company has now prevented that specific kind of assault (though, understandably, it wouldn't specify how). But what Amazon hasn't solved—what nobody has yet solved—is the security problem inherent in the size and structure of clouds.

Cloud computing—programs and services delivered over the Internet—is rapidly changing the way we use computers (*see Briefing, July/August 2009, and "Clouds, Ascending," p. 41*). Gmail, Twitter, and Facebook are all cloud applications, for example. Web-based infrastructure services like Amazon's—as well as versions from vendors such as Rackspace—have attracted legions of corporate and institutional customers drawn by their efficiency and low cost. The clientele for Amazon's cloud services now includes the *New York Times* and Pfizer. And Google's browser and forthcoming operating system (both named Chrome) mean to provide easy access to cloud applications.

Even slow-moving government agencies are getting into the act: the City of Los Angeles uses Google's Apps service for e-mail and other routine applications, and the White House recently launched www.apps.gov to encourage federal agencies to use cloud services. The airline, retail, and financial industries are examples of those that could benefit from cloud computing, says Dale Jorgenson, a Harvard economist and expert on the role of information technology in national productivity. "The focus of IT innovation has shifted from hardware to software applications," he says. "Many of these applications are going on at a blistering pace, and cloud computing is going to be a great facilitative technology for a lot of these people."

Of course, none of this can happen unless cloud services are kept secure. And they are not without risk. When thousands of different clients use the same hardware at large scale, which is the key to the efficiency that cloud computing provides, any breakdowns or hacks could prove devastating to many. "Today you have these huge, mammoth cloud providers with thousands and thousands of companies cohosted in them," says Radu Sion, a computer scientist at the State University of New York at Stony Brook. "If you don't have everybody using the cloud, you can't have a cheap service. But when you have everybody using the clouds, you have all these security issues that you have to solve suddenly."

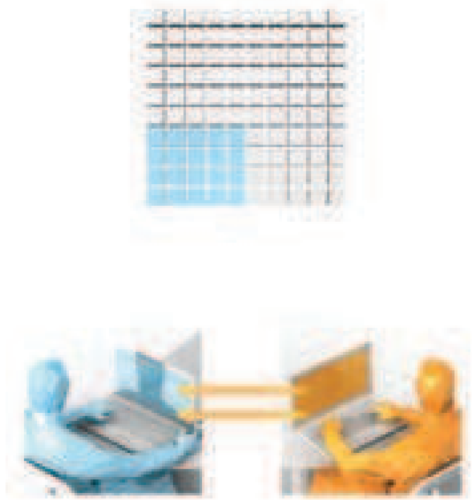
CLOUD CRISES

Cloud computing actually poses several separate but related security risks. Not only could stored data be stolen by hackers or lost to breakdowns, but a cloud provider might mishandle data—or be forced to give it up in response to a subpoena. And it's clear enough that such security breaches are not just the stuff of academic experiments. In 2008, a single corrupted bit in messages between servers used by Amazon's Simple Storage Service (S3), which provides online data storage by the gigabyte, forced the system to shut down for several hours. In early 2009, a hacker who correctly guessed the answer to a Twitter employee's personal e-mail security question was able to grab all the documents in the Google Apps account the employee used. (The hacker gleefully sent some to the news media.) Then a bug compromised the sharing restrictions placed on some users' documents in Google Docs. Distinctions were erased; anyone with whom you shared document access could also see documents you shared with anyone else. And in October, a million T-Mobile Sidekick smart phones lost data after a server failure at Danger, a subsidiary of Microsoft that provided the storage. (Much of the data was later recovered.) Especially with applications delivered through public clouds, "the surface area of attack is very, very high," says Peter Mell, leader of the cloud security team at the National Institute of Standards and Technology (NIST) in Gaithersburg, MD. "Every customer has access to every knob and widget in that application. If they have a single weakness, [an attacker may] have access to all the data."

SNOOPING INSIDE AMAZON'S CLOUD

Researchers recently figured out a way to place malicious "virtual machines" on the servers hosting virtual machines assigned to intended victims in Amazon's Elastic Compute Cloud, which they say could make it possible for an attacker to steal data. Amazon says it has since prevented this kind of attack and that the threat of data theft had only been theoretical. Here's how the researchers did it.

1. The researchers hired "victim" virtual machines (VMs) from Amazon's cloud and noted the machines' IP addresses. They learned that if they bought multiple VMs at nearly the same time, those machines would have similar IP addresses, indicating that they were probably hosted on the same server.



2. They realized that to increase the odds of placing a malicious VM on the same server as a victim VM, they would have to force a victim to hire a machine at a certain time. One way to do this, they say, would be to bombard the victim's website with requests, forcing the victim to increase capacity.

3. As the victim hired new VMs to handle the extra demand, the attacker also hired VMs. By checking IP addresses, the researchers found that the victims and attackers wound up on the same Amazon servers 40 percent of the time.

4. Once the malicious VMs were on the same server as the victim's VMs, the researchers were able to show they could monitor the victim's use of computing resources. They said outright data theft would also be possible, though they didn't take this step.

Source: Ristenpart et al, 2009. "Hey, you, get off of my cloud: exploring information leakage in third-party compute clouds." In Proceedings of the 16th ACM Conference on Computer and Communications Security.

BRYAN CHRISTIE DESIGN

To all this, the general response of the cloud industry is: clouds are more secure than whatever you're using now. Eran Feigenbaum, director of security for Google Apps, says cloud providers can keep ahead of security threats much more effectively than millions of individuals and thousands of companies running their own computers and server rooms. For all the hype over the Google Docs glitch, he points out, it affected less than .05 percent of documents that Google hosted. "One of the benefits of the cloud was the ability to react in a rapid, uniform manner to these people that were affected," he says. "It was all corrected without users having to install any software, without any server maintenance." Think about the ways security can be compromised in traditional settings, he adds: two-thirds of respondents to one survey admitted to having mislaid USB keys, many of them holding private company data; at least two million laptops were stolen in the United States in 2008; companies can take three to six months to install urgent security patches, often because of concern that the patches will trigger new glitches. "You can't get 100 percent security and still

manage usability," he says. "If you want a perfectly secure system, take a computer, disconnect it from any external sources, don't put it on a network, keep it away from windows. Lock it up in a safe."

But not everyone is so sanguine. At a computer security conference last spring, John Chambers, the chairman of Cisco Systems, called cloud computing a "security nightmare" that "can't be handled in traditional ways." At the same event, Ron Rivest, the MIT computer scientist who coinvented the RSA public-key cryptography algorithm widely used in e-commerce, said that the very term *cloud computing* might better be replaced by *swamp computing*. He later explained that he meant consumers should scrutinize the cloud industry's breezy security claims: "My remark was not intended to say that cloud computing really is 'swamp computing' but, rather, that terminology has a way of affecting our perceptions and expectations. Thus, if we stop using the phrase *cloud computing* and started using *swamp computing* instead, we might find ourselves being much more inquisitive about the services and security guarantees that 'swamp computing providers' give us."

CLOUD INFRASTRUCTURE More and more computing services are being delivered over the Internet. Behind the technology are huge remote data centers like these two football-field-sized buildings that Google operates in The Dalles, OR, shown during their construction four years ago.

A similar viewpoint, if less colorfully expressed, animates a new effort by NIST to define just what cloud computing is and how its security can be assessed. "Everybody has confusion on this topic," says Peter Mell; NIST is on its 15th version of the document defining the term. "The typical cloud definition is vague enough that it encompasses all of existing modern IT," he says. "And trying to pull out unique security concerns is problematic." NIST hopes that identifying these concerns more clearly will help the industry forge some common standards that will keep data more secure. The agency also wants to make clouds interoperable so that users can more easily move their data from one to another, which could lead to even greater efficiencies.

Given the industry's rapid growth, the murkiness of its current security standards, and the anecdotal accounts of breakdowns, it's not surprising that many companies still look askance at the idea of putting sensitive data in clouds. Though security is currently fairly good, cloud providers will have to prove their reliability over the long term, says Larry Peterson, a computer scientist at Princeton University who directs an Internet test bed called the PlanetLab Consortium. "The cloud provider may have appropriate security mechanisms," Peterson says. "But can I trust not only that he will protect my data from a third party but that he's not going to exploit my data, and that the data will be there five years, or 10 years, from now? Yes, there are security issues that need attention. But technology itself is not enough. The technology here may be out ahead of the comfort and the trust."

In a nondescript data center in Somerville, MA, just outside Boston, lies a tangible reminder of the distrust that Peterson is talking about. The center is owned by a small company called 2N+1, which offers companies chilled floor space, security, electricity, and connectivity. On the first floor is a collection of a dozen black cabinets full of servers. Vincent Bono, a cofounder of 2N+1, explains these are the property of his first client, a national bank. It chose to keep its own servers rather than hire a cloud. And for security, the bank chose the tangible kind: a steel fence.

ENCRYPTING THE CLOUD

Cloud providers don't yet have a virtual steel fence to sell you. But at a minimum, they can promise to keep your data on servers in, say, the United States or the European Union, for regulatory compliance or other reasons. And they are working on virtual walls: in August, Amazon announced plans to offer a "private cloud" service that ensures more secure passage of data from a corporate network to Amazon's servers. (The company said this move was not a response to the research by the San Diego and MIT group. According to Adam Selipsky, vice president of Amazon Web Services, the issue was simply that "there is a set of customers and class of applications asking for even more enhanced levels of security than our existing services provided.")

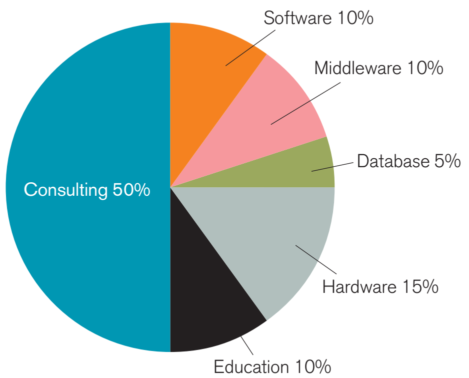
Meanwhile, new security technologies are emerging. A group from Microsoft, for example, has proposed a way to prevent users of one virtual machine on a server from gleaning information by monitoring the use of shared cache memory by another virtual machine on the same server, something that the San Diego and MIT researchers suggested was possible. And researchers at IBM have proposed a new kind of security mechanism that would, in

CRAIG MITCHELL DYER/GETTY IMAGES

CLOUDS, ASCENDING

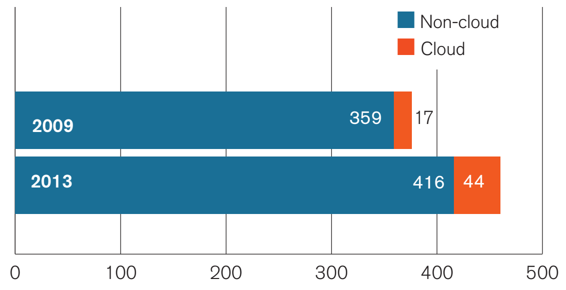
Traditional IT is complex to deploy and carries high overhead costs ...

COST BREAKDOWN



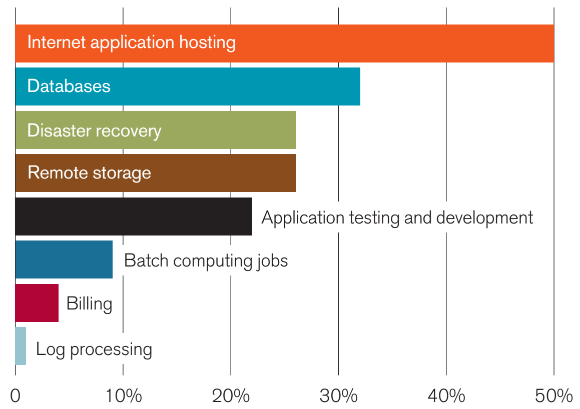
... but cloud computing services are highly efficient, which is one reason they're growing fast.

WORLDWIDE IT SPENDING PROJECTIONS, IN BILLIONS



Until questions about privacy and security are dealt with, however, companies will continue to reserve cloud services for the least sensitive tasks.

HOW PUBLIC CLOUD SERVICES ARE USED



SOURCES: MERRILL LYNCH (APPLICATION DEPLOYMENT); IDC (IT SPENDING); 451 GROUP (USES OF CLOUDS)

essence, frisk new virtual machines as they entered the cloud. Software would monitor each one to see how it operates and ensure its integrity, in part by exploring its code. Such technologies could be ready for market within two or three years.

But fully ensuring the security of cloud computing will inevitably fall to the field of cryptography. Of course, cloud users can already encrypt data to protect it from being leaked, stolen, or—perhaps above all—released by a cloud provider facing a subpoena. This approach can be problematic, though. Encrypted documents stored in a cloud can't easily be searched or retrieved, and it's hard to perform calculations on encrypted data. Right now, users can get around these problems by leaving their information in the cloud unencrypted ("in the clear") or pulling the encrypted material back out to the safety of their own secure computers and decrypting it when they want to work with it. As a practical matter, this limits the usefulness of clouds. "If you have to actually download everything and move it back to its original place before you can use that data, that is unacceptable at the scale we face today," says Kristin Lauter, who heads the cryptography research group at Microsoft Research.

Emerging encryption technologies, however, could protect data in clouds even as users search it, retrieve it, and perform calculations on it. And this could make cloud computing far more attractive to industries such as banking and health care, which need security for sensitive client and patient data. For starters, several research groups have developed ways of using hierarchical encryption to provide different levels of access to encrypted cloud data. A patient, for example, could hold a master key to his or her own electronic medical records; physicians, insurers, and others could be granted subkeys providing access to certain parts of that information.

Ideally, we'd make it more practical to work with sensitive data that needs to be encrypted, such as medical records, so that unintended viewers couldn't see it if it were exposed by a hack or a glitch at the cloud provider. "The general theme of cloud computing is that you want to be able to outsource all kinds of functionality but you don't want to give away your privacy—and you need very versatile cryptography to do that," says Craig Gentry, a cryptography researcher at IBM's Watson Research Center in Yorktown, NY. "It will involve cryptography that is more complicated than we use today."

To find and retrieve encrypted documents, groups at Carnegie Mellon University, the University of California, Berkeley, and elsewhere are working on new search strategies that start by tagging encrypted cloud-based files with encrypted metadata. To perform a search, the user encrypts search strings using mathematical functions that enable strings to find matches in the encrypted metadata. No one in the cloud can see the document or even the search term that was used. Microsoft Research recently introduced a theoretical architecture that would stitch together several crytographic

technologies to make the encrypted cloud more searchable.

The problem of how to manipulate encrypted data without decrypting it, meanwhile, stumped researchers for decades until Gentry made a breakthrough early in 2009. While the underlying math is a bit thick, Gentry's technique involves performing calculations on the encrypted data with the aid of a mathematical object called an "ideal lattice." In his scheme, any type of calculation can be performed on data that's securely encrypted inside the cloud. The cloud then releases the computed answers—in encrypted form, of course—for users to decode outside the cloud. The downside: the process eats up huge amounts of computational power, making it impractical for clouds right now. "I think one has to recognize it for what it is," says Josyula Rao, senior manager for security at IBM Research. "It's like the first flight that the Wright Brothers demonstrated." But, Rao says, groups at IBM and elsewhere are working to make Gentry's new algorithms more efficient.

RISKS AND BENEFITS

If cloud computing does become secure enough to be used to its full potential, new and troubling issues may arise. For one thing, even clouds that are safe from ordinary hackers could become central points of Internet control, warns Jonathan Zittrain, the cofounder of Harvard's Berkman Center for Internet and Society and the author of *The Future of the Internet—and How to Stop It*. Regulators, courts, or overreaching government officials might see them as convenient places to regulate and censor, he says.

What's more, cloud providers themselves could crack down on clients if, say, copyright holders apply pressure to stop the use of file-sharing software. "For me," Zittrain says, "the biggest issue in cloud security is not the Sidekick situation where Microsoft loses your data." More worrisome to him are "the increased ability for the government to get your stuff, and fewer constitutional protections against it; the increased ability for government to censor; and increased ability for a vendor or government to control innovation and squash truly disruptive things."

Zittrain also fears that if clouds dominate our use of IT, they may turn into the kinds of "walled gardens" that characterized the Internet in the mid-1990s, when companies such as Compuserve, Prodigy, and AOL provided limited menus of online novelties such as news, e-commerce, and e-mail to the hoi polloi. Once people pick a cloud and applications they like, he says—Google Apps, for example—they may find they have limited access to great apps in other clouds, much as Facebook users can't network with people on MySpace.

But such concerns aren't stopping the ascendance of the cloud. And if cloud security is achieved, the benefits could be staggering. "There is a horrendous amount of computing and database management where cloud computing is clearly relevant," says Harvard's Dale Jorgenson. Imagine if today's emerging online repositories for personal health data, such as Google Health and

> **"Clouds are systems. And with systems, you have to think hard and know how to deal with issues in that environment. The scale is so much bigger, and you don't have the physical control."**

Microsoft HealthVault, could link up with the growing number of electronic records systems at hospitals in a way that keeps private data protected at all times. The resulting medical megacloud could spread existing applications cheaply and efficiently to all corners of the medical profession. Doctors could easily compare patients' MRI scans, for example, with those of other patients around the country, and delve into vast databases to analyze the efficacy of treatments and prevention measures *(see "Prescription: Networking," November/December 2009 and at www.technologyreview.com)*. "The potential there is enormous, because there are a couple of transformations that may occur in medicine in the near future from vast collections of medical records," says Ian Foster, a computer scientist who leads the Computation Institute at Argonne National Laboratory and the University of Chicago. Today, he points out, individuals are demanding access to their own medical information while medical institutions seek new sources of genomic and other data. "The two of those, together, can be powered by large-scale sharing of information," he says. "And maybe you can do it in the cloud. But it has particularly challenging security problems."

This isn't the first time a new information technology has offered profound benefits while raising potentially intolerable security risks. The advent of radio posed similar issues a century ago, says Whitfield Diffie, one of the pioneers of public-key cryptography, who is now a visiting professor at Royal Holloway College at the University of London. Radio was so much more flexible and powerful than what it replaced—the telegraph—that you *had* to adopt it to survive in business or war. The catch was that radio can be picked up by anyone. In radio's case, fast, automated encryption and decryption technologies replaced slow human encoders, making it secure enough to realize its promise. Clouds will experience a similar evolution. "Clouds are systems," says NIST's Peter Mell. "And with systems, you have to think hard and know how to deal with issues in that environment. The scale is so much bigger, and you don't have the physical control. But we think people should be optimistic about what we can do here. If we are clever about deploying cloud computing with a clear-eyed notion of what the risk models are, maybe we *can* actually save the economy through technology." TR

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.

Trading Shares in Milliseconds

Today's stock market has become a world of automated transactions executed at lightning speed. This high-frequency trading could make the financial system more efficient, but it could also turn small mistakes into catastrophes.

By BRYANT URSTADT

If Manoj Narang is about to bring down the markets, he's certainly relaxed about it. Narang, who wears a goatee and wire-frame glasses, is casually dressed in a brown shirt and dark gray sweatshirt. Sitting on a swivel chair with one leg tucked under the other, he seems positively composed, especially for a man who has just bought and sold 15 million shares with a total value of $600 million. For Narang, however, such volume represents just the start of a normal day. Though it's about noon on a Friday morning, he has barely begun.

Narang is the head of Tradeworx, a hedge fund and financial-technology firm that makes purely automated trades; all decisions are reached and acted on at near light speed by computers running preprogrammed algorithms. "Actually, we run two businesses," he says. "The first trades in and out of shares in about a second and holds them for an average of two or three days. That's the medium-speed fund. The high-speed fund could make thousands of trades a second and holds them for a matter of minutes."

By the end of the day, his computers will have bought and sold about 60 million to 80 million shares, with the heaviest activity in the last hour of trading, from three to four in the afternoon. Tradeworx and similar firms around the country will race to close billions of bets that hinge on things like tiny differences between the prices of shares in an exchange-traded fund holding the S&P 500 and the individual shares that make up the same index. The profits go to the company with the fastest hardware and the best algorithms—advantages that enable it to spot and exploit subtle market patterns ahead of everyone else. At the end of a typical day, the Tradeworx high-speed business holds no shares at all. Come Monday, Narang will look to trade millions more shares. It seems like a lot, and it is, but Narang estimates that he's probably only somewhere in the middle of the top 50 traders by volume.

Just five years ago, automated trades made up about 30 percent of the market, and few of those moved as quickly as today's trades do. Since then, however, automated trading has become much more widespread, and much quicker. Narang acknowledges starting his ultrafast group as a defensive maneuver when he began to notice faster traders eroding the performance of his medium-speed strategy. Now the medium-speed fund is adopting the techniques he developed in the ultrafast fund.

The Tabb Group, a consultancy based in Westborough, MA, estimates that high-frequency automated trading now accounts for 61 percent of the more than 10 billion shares traded daily across the numerous exchanges that make up the U.S. market. Tabb estimates profits from high-frequency trading in the first nine months of last year at $8 billion or more. With the rise of automation, the bulk of U.S. stock trading has moved from the once-crowded floor of Manhattan's New York Stock Exchange (NYSE) to silent server farms run by exchanges and broker-dealers across the country: the proportion of all trades that the NYSE handles has shrunk from 80 percent in 2005 to 40 percent today. Trading is now essentially a virtual art, and its practitioners put such a premium on speed that NASDAQ has considered issuing equal 100-foot lengths of cable to the brokers who send orders to its exchange servers. (Though Narang and his team program their algorithms on PCs in their own office, actual trading is done through brokers' servers located on the premises of an exchange—NASDAQ, the NYSE, and dozens of others.)

The NYSE itself is just finishing construction of a 400,000-square-foot data center in Mahwah, NJ. The new com-

Photographs by STEVE MOORS

IN A HURRY Manoj Narang, founder and head of Tradeworx, buys and sells millions of shares every day, using algorithms that often execute thousands of trades per second.

plex, slated to open in the spring, will have enough computing power to handle every trade on every market in the world, though the exchange will probably have trouble grabbing much of that business back. Hardware used at the facility will operate at a 40-gigabyte-per-second standard, enabling it to handle as many as a million messages a second. (The limit, in many cases, is not the speed at which the information travels but the ability of switches to route it quickly enough.)

The Tradeworx office in Red Bank, NJ, a wealthy shore town about an hour from Manhattan, is a far cry from Wall Street. A quieter place would be hard to imagine. About a dozen employees, most of whom graduated from top-tier schools with degrees in science, math, or engineering, work largely in silence. On this morning, as those 15 million shares come and go, the Tradeworx staff says hardly a word.

In Narang's office, the shades are drawn, the better to read a large monitor on one wall. There are no tickers scrolling by, no flashing updates on the value of the Dow Jones index. Narang's strategy is "market neutral," meaning that when it works–and it usually does–he makes money no matter which way the market goes. His profits don't depend on whether share prices rise or fall; instead, he relies on a set of algorithms that can find and instantly take advantage of tiny, fleeting movements in trading activity. On the wall across from the window is a whiteboard filled with code: a scribbled flowchart in different colors, with variables and occasional amounts in boxes and the words *buy* or *sell*. In the middle of the monitor is a large number in a box, going up and down but mainly up. That is Tradeworx's profit so far that morning.

BUY! SELL! In Tradeworx's offices in Red Bank, NJ, employees work in near silence, programming the algorithms that allow the company to profitably execute its speedy trading programs. Far from Wall Street, firms that specialize in this high-frequency trading represent an increasingly large portion of activity in the financial markets.

A CRASH WAITING TO HAPPEN?

High-frequency trading has become controversial, with critics charging that traders are manipulating the market, taking advantage of the little guy, and even courting a full-scale financial meltdown. The critical voices are growing louder and more united, and they're reaching higher up the rungs of power. In September, Senator Edward Kaufman (D–Delaware), speaking on the floor of the U.S. Senate, worried that the United States was moving toward a situation with "one market for huge-volume, high-speed players, who can take advantage of every loophole for profit, and another market for retail investors, whose orders are seemingly filled as an afterthought." The Securities and Exchange Commission has recently proposed a rule to eliminate one controversial tactic of high-frequency traders: the "flash trade," in which exchanges alert designated traders to incoming orders. Critics call it a variation of front-running, an old (and illegal) practice that involved traders buying and selling in advance of large orders.

But accusations of unfairness are not the only issue. Any trend that becomes as dominant as high-frequency trading should be studied to consider potentially serious side effects, warns Paul Wilmott, the publisher of the quantitative-finance journal *Wilmott* and the founder of the mathematical-finance diploma program at the University of Oxford. "High-frequency trading is the latest bandwagon, and everyone is jumping on board," he says. "Wall Street always piles on to the next thing, and it always blows up."

Wilmott, a self-described "instinctive contrarian" who correctly warned in 2000 that the derivatives market was dangerously unstable, sees particular threats from this trend. The increasing dominance of algorithmic trading and the growing speed of execution, he says, could cause tiny price changes to snowball, rolling down the hill at exponentially increasing speed–either because the machines are trading too fast or because too many funds are trading in the same style. "The potential is there for a crash to happen quite quickly," he says.

Bernard Donefer, who oversaw electronic trading at Fidelity Investments from 1996 to 2002 and now teaches about information technology in financial markets at Baruch College's business

school in New York, worries that high-speed algorithmic trading will lead to a smaller-scale version of the crash of 1987, when the market dropped 22 percent in one day. Many now blame that crash on simple automated "portfolio insurance" systems, which were meant to keep a fund's holdings from losing more than a preset amount of value by automatically selling shares when the price dropped by a certain amount. They had their roots in a practice used by floor traders: the "stop loss" order, which initiates the sale of a given share if it falls below a given price. But the herd of computers issuing stop-loss orders created a stampede that pushed the then-dominant floor traders to sell as well. Donefer worries that if such a sell-off happened now, it would happen many times faster.

While such "forced selling" can be the result of forethought (misguided or not), it can also start with a mistake: pressing an extra button (what traders call "fat-finger syndrome") or botching the code that drives an automated algorithm. In 2003, shares of Corinthian Colleges, a company that manages for-profit educational institutions, plummeted when faulty code or human error caused a computer to begin selling shares its user did not have. The system had been programmed to sell if the security returned to the price at which it had been bought. When that time came, the computer sold the shares the customer held and just kept going. In 12 minutes, it sold short nearly three million shares at prices from $57.50 all the way down to $39.50. In a market dominated by high-frequency trading, such glitches could mushroom within seconds.

Even some high-frequency traders worry about what Donefer calls "algos gone wild." John Jacobs, the COO of the New York City–based Lime Brokerage, wrote the SEC in 2009 to voice concerns over the proliferation of brokers who allow major clients to engage in high-frequency trading without validating their margins—that is to say, without making sure they actually have enough money to back a trade. Lime provides high-speed market access and order validation to hedge funds and other traders, some of whom cannot, or don't want to, place their own servers on an exchange floor. In his position, Jacobs regularly sees algorithms executing more than 1,000 orders a second. At that rate, one algorithm trading the wrong way could execute 120,000 orders in two minutes. At 1,000 shares per order and an average price of, say, $20 a share, that's $2.4 billion in unintended trades. In his letter, Jacobs warned of "the potential for trading-induced multiple domino bankruptcies." He cautioned that "unrestrained computer-generated trading has the potential to create catastrophic economic damage to the U.S. national market system."

> One executive warns of "the potential for trading-induced multiple domino bankruptcies." He says that "unrestrained computer-generated trading has the potential to create catastrophic economic damage to the U.S. national market system."

PENNY PINCHING

The players in high-frequency trading are many and varied. Some are institutional investors like pension funds, endowments, and mutual funds; others are brokerages or trading desks at banks, using the banks' own money. Enormous hedge funds like the Citadel Investment Group in Chicago use these techniques, and so do startups like PhaseCapital in Boston, which began trading with just the partners' money in the spring. Designated "market makers"—traders licensed by an exchange to create a stable market in a security by making it available to both buyers and sellers in an orderly fashion—use high-frequency strategies to fill orders and to hedge positions, constantly rebalancing inventory so as not to get caught with too many or too few shares. And the field will only grow. Companies now offer high-frequency packages that include software, brokerage hookups, and as much consulting as you can afford.

Indeed, in many ways, practices associated with high-frequency trading have become a routine part of how the market operates. When a customer places a trade through a Charles Schwab account, for example, that order is likely to be handled by a high-speed algorithm. Institutional traders like Fidelity, which buy large blocks of shares for their mutual funds, use algorithmic trading to split their enormous orders into blocks of 100 to 300 shares so that other traders don't recognize the true demand and take advantage of that knowledge for their own profit.

Hedge funds with high-frequency operations, like Tradeworx, work between and around the institutional traders and the market makers, and against each other, attempting to profit by anticipating the moves of others. Their reliance on statistical patterns and quantitative analysis has won them the name of "quant funds." (A quant fund typically holds a portfolio derived from statistical analysis, but its trades may take place over months as well as microseconds. Though most high-frequency funds are quant funds, not all quant funds trade at high frequency.) The explosion in high-speed automated trading has engendered a massive buildup in technology; Renaissance Technologies, a hedge fund based in East Setauket, NY, boasts that its computing power is

CASHING IN On a recent morning, Tradeworx bought and sold 15 million shares before noon. Speed means profits as the company races against other firms using similar high-frequency tactics to take advantage of small movements in the markets. A monitor (lower right) at Tradeworx's offices keeps track of the net trading operations during the day. It generally ticks up.

equal to that of the Lawrence Livermore National Laboratory.

Just one example of what speed can do explains a lot about how high-frequency trading works and why it angers some observers, as Joseph Saluzzi and Sal Arnuk, the principals of the New Jersey–based Themis Trading, made clear in their 2008 white paper "Toxic Equity Trading Order Flow on Wall Street." Imagine that a mutual fund enters a buy order, telling its computer to start by offering the current market price of $20.00 a share but to take any asked price up to $20.03. A high-speed trader, Saluzzi and Arnuk explained, can use a "predatory algo" to identify that limit by "pinging" the market with sell orders that are issued in fractions of a second and canceled just as fast. It might start at $20.05 and work its way down to $20.03, canceling and reordering until the mutual fund bites. The trader then buys closer to the current $20.00 price from another, slower investor, reselling to the fund at $20.03. Because the high-frequency trader has a speed advantage, he is able to do all this before the slower party can catch up and offer shares for $20.01. This speedy player has found the buyer's limit, gathered up and sold an order, and snipped a few pennies off for himself.

LIQUIDITY AND ORDER

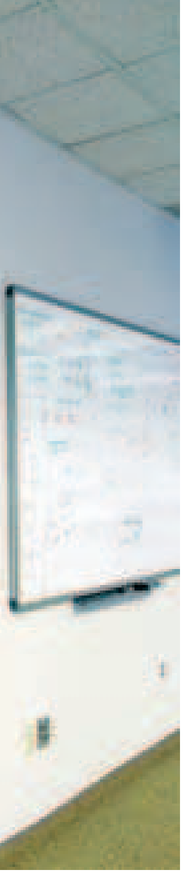
Picking up all those pennies can be risky, Narang says, but he makes what he considers an important distinction. "There is risk, definitely, but quant funds like us take it all," he says. "If a quant meltdown happens, it won't affect the retail investor."

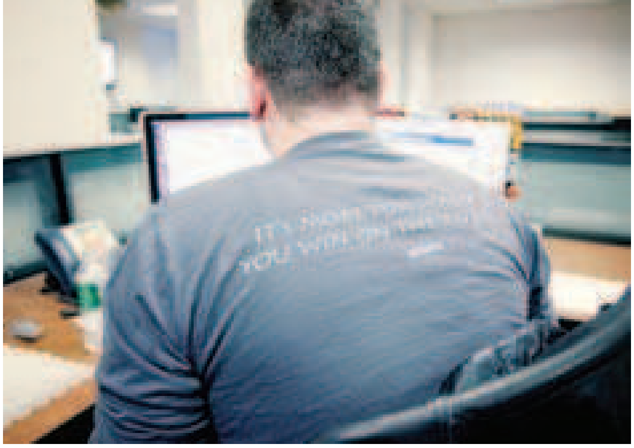
Narang turns to his computer and brings up two graphs, superimposing one on the other. The first shows the erratic up-and-down crawl of the S&P 500, the value of the largest 500 companies in the United States, over the last six years. The second shows Tradeworx's profit and loss over the same period. It is a steady march up; in Tradeworx's worst year, it made 15 percent. "All [high-frequency] funds have a profit-and-loss line like this," he says. Then he magnifies the graphs to show just the weeks around August 2007, when many quant funds self-destructed as they sold off their portfolios to meet increasing margin calls *(see "The Blow-Up," November/December 2007 and at www.technologyreview.com)*. In those days, his P&L dropped by 7 percent, and many other funds saw similar losses. But the S&P 500, overall, was little affected.

"And here's the second quant meltdown, in January of '08," Narang says, zooming out and then in on another blip in the graph, showing the value of the S&P 500 when a second, albeit smaller, dislocation occurred. "It's tiny. You can hardly see it. That's because funds running quantitative strategies are mostly market neutral. When we take a position, we're always balanced somewhere else, and when we unwind, it doesn't affect the market either." By this he means that forced selling by quant funds may be painful for the funds themselves, but that pain is barely reflected in the market, because the funds' long and short positions—positive and negative bets on the direction of given securities—cancel one another out. "We don't take from the retail guy," he says. "We make the market more efficient. Things are better for the retail investor because of high-frequency trading."

Narang, and academics like Donefer, say that high-frequency traders are making money by delivering a service: liquidity. In today's highly decentralized market, defenders say, their systems are simply the most efficient way to match buyers and sellers. And because they can capitalize on small differences between the prices at which a seller is willing to sell and a buyer is willing to buy, those

Take a snapshot of this code with your smart phone to see a special report on smarter IT. For the software, visit www.neoreader.com. Watch an interview with Tradeworx CEO Manoj Narang: **www.technologyreview.com/highspeedtrading**





differences stay small. The upshot is that retail buyers pay a little less to buy a share and can sell it for a little more. Indeed, since electronic trading has come to dominate the market, spreads between buying and selling prices have decreased dramatically, and so have fees. Ten years ago an investor might have paid $150 in fees to trade 500 shares with a broker, facing a spread of maybe a dime on each share. Today's retail investors pay $10, with spreads of a penny or so in most big stocks, and most of their trades are filled almost instantly.

Understanding how high-frequency trading improves liquidity explains a lot about why many such traders do well when the market is plunging or volatile, as it was last year. "We don't make volatility happen," says Narang. "We reduce it, but it is how we make our money. We create order. When the markets are disorderly, we make a lot of money, but we are doing it by restoring the markets to order."

If Narang is right, the new ways are good for the retail investor. But the argument that high-frequency funds improve liquidity, as if they were providing a public service, is disturbingly reminiscent of the justifications offered by hedge funds and banks that created complicated derivatives in the years leading up to the recent crash. When things went bad in that case, the liquidity disappeared—along with many of the funds invested in them, and much of the investors' money. And this type of history doggedly repeats itself. Wilmott, for one, is not convinced that high-frequency trading is useful to the economy. "People have to say things are fine because they're being rewarded for it," he suggests.

At least for now, though, things are calm, and the spreads are narrow. After lunch, Narang's day at Tradeworx starts to get busier as hundreds of high-frequency funds jostle to close out their positions to their best advantage. Narang says good-bye at the door, his words the only sound in the quiet office. On the wall behind him, Tradeworx's daily profit-and-loss line still ticks up and down, but mostly up. TR

BRYANT URSTADT IS A WRITER BASED IN NEW YORK.

The Geoengineering Gambit

For years, radical thinkers have proposed risky technologies that they say could rapidly cool the earth and offset global warming. Now a growing number of mainstream climate scientists say we may have to consider extreme action despite the dangers.

By KEVIN BULLIS

Rivers fed by melting snow and glaciers supply water to over one-sixth of the world's population—well over a billion people. But these sources of water are quickly disappearing: the Himalayan glaciers that feed rivers in India, China, and other Asian countries could be gone in 25 years. Such effects of climate change no longer surprise scientists. But the speed at which they're happening does. "The earth appears to be changing faster than the climate models predicted," says Daniel Schrag, a professor of earth and planetary sciences at Harvard University, who advises President Obama on climate issues.

Atmospheric levels of carbon dioxide have already climbed to 385 parts per million, well over the 350 parts per million that many scientists say is the upper limit for a relatively stable climate. And despite government-led efforts to limit carbon emissions in many countries, annual emissions from fossil-fuel combustion are going up, not down: over the last two decades, they have increased 41 percent. In the last 10 years, the concentration of carbon dioxide in the atmosphere has increased by nearly two parts per million every year. At this rate, they'll be twice preindustrial levels by the end of the century. Meanwhile, researchers are growing convinced that the climate might be more sensitive to greenhouse gases at this level than once thought. "The likelihood that we're going to avoid serious damage seems quite low," says Schrag. "The best we're going to do is probably not going to be good enough."

This shocking realization has caused many influential scientists, including Obama advisors like Schrag, to fundamentally change their thinking about how to respond to climate change. They have begun calling for the government to start funding research into geoengineering—large-scale schemes for rapidly cooling the earth.

Strategies for geoengineering vary widely, from launching trillions of sun shields into space to triggering vast algae blooms in oceans. The one that has gained the most attention in recent years involves injecting millions of tons of sulfur dioxide high into the atmosphere to form microscopic particles that would shade the planet. Many geoengineering proposals date back decades, but until just a few years ago, most climate scientists considered them something between high-tech hubris and science fiction. Indeed, the subject was "forbidden territory," says Ronald Prinn, a professor of atmospheric sciences at MIT. Not only is it unclear how such engineering feats would be accomplished and whether they would, in fact, moderate the climate, but most scientists worry that they could have disastrous unintended consequences. What's more, relying on geoengineering to cool the earth, rather than cutting greenhouse-gas emissions, would commit future generations to maintaining these schemes indefinitely. For these reasons, mere discussion of geoengineering was considered a dangerous distraction for policy makers considering how to deal with global warming. Prinn says that until a few years ago, he thought its advocates were "off the deep end."

It's not just a fringe idea anymore. The United Kingdom's Royal Society issued a report on geoengineering in September that outlined the research and policy challenges ahead. The National Academies in the United States are working on a similar study. And John Holdren, the director of the White House Office of Science and Technology Policy, broached the idea soon after he was appointed. "Climate change is happening faster than anyone previously predicted," he said during one talk. "If we get sufficiently desperate, we may try to engage in geoengineering to try to create cooling effects." To prepare ourselves, he said, we need to understand the possibilities and the possible side effects. Even the U.S. Congress has now taken an interest, holding its first hearings on geoengineering in November.

Geoengineering might be "a terrible idea," but it might be better than doing nothing, says Schrag. Unlike many past advocates, he doesn't think it's an alternative to reducing greenhouse-gas emissions. "It's not a techno-fix. It's not a Band-Aid. It's a tourniquet,"

Photographs by MAURICIO ALEJO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he says. "There are potential side effects, yes. But it may be better than the alternative, which is bleeding to death."

SUNDAY STORMS

The idea of geoengineering has a long history. In the 1830s, James Espy, the first federally funded meteorologist in the United States, wanted to burn large swaths of Appalachian forest every Sunday afternoon, supposing that heat from the fires would induce regular rainstorms. More than a century later, meteorologists and physicists in the United States and the Soviet Union separately considered a range of schemes for changing the climate, often with the goal of warming up northern latitudes to extend growing seasons and clear shipping lanes through the Arctic.

In 1974 a Soviet scientist, Mikhail Budyko, first suggested what is today probably the leading plan for cooling down the earth: injecting gases into the upper reaches of the atmosphere, where they would form microscopic particles to block sunlight. The idea is based on a natural phenomenon. Every few decades a volcano erupts so violently that it sends several millions of tons of sulfur—in the form of sulfur dioxide—more than 10 kilometers into the upper reaches of the atmosphere, a region called the stratosphere. The resulting sulfate particles spread out quickly and stay suspended for years. They reflect and diffuse sunlight, creating a haze that whitens blue skies and causes dramatic sunsets. By decreasing the amount of sunlight that reaches the surface, the haze also lowers its temperature. This is what happened after the 1991 eruption of Mount Pinatubo in the Philippines, which released about 15 million tons of sulfur dioxide into the stratosphere. Over the next 15 months, average temperatures dropped by half a degree Celsius. (Within a few years, the sulfates settled out of the stratosphere, and the cooling effect was gone.)

Scientists estimate that compensating for the increase in carbon dioxide levels expected over this century would require pumping between one million and five million tons of sulfur into the stratosphere every year. Diverse strategies for getting all that sulfur up there have been proposed. Billionaire investor Nathan Myhrvold, the former chief technology officer at Microsoft and the founder and CEO of Intellectual Ventures, based in Bellevue, WA, has thought of several, one of which takes advantage of the fact that coal-fired power plants already emit vast amounts of sulfur dioxide. These emissions stay close to the ground, and rain washes them out of the atmosphere within a couple of weeks. But if the pollution could reach the stratosphere, it would circulate for years, vastly multiplying its impact in reflecting sunlight. To get the sulfur into the stratosphere, Myhrvold suggests, why not use a "flexible, inflatable hot-air-balloon smokestack" 25 kilometers tall? The emissions from just two coal-fired plants might solve the problem, he says. He estimates that his solution would cost less than $100 million a year, including the cost of replacing balloons damaged by storms.

Not surprisingly, climate scientists are not ready to sign off on such a scheme. Some problems are obvious. No one has ever tried to build a 25-kilometer smokestack, for one thing. Moreover, scientists don't understand atmospheric chemistry well enough to be sure what would happen; far from alleviating climate change, shooting tons of sulfates into the stratosphere could have disastrous consequences. The chemistry is too complex for us to be certain, and climate models aren't powerful enough to tell the whole story.

"We know Pinatubo cooled the earth, but that's not the question," Schrag says. "Average temperature is not the only issue." You've also got to account for regional variations in temperature and effects on precipitation, he explains—the very things that climate models are notoriously bad at accounting for. Prinn concurs: "If we lower levels of sunlight, we are unsure of the exact response of the climate system to doing that, for the same reason that we don't know exactly how the climate will respond to a particular level of greenhouse gases." He adds, "That's the big issue. How can you engineer a system you don't fully understand?"

> "If we lower levels of sunlight, we are unsure of the exact response of the climate system to doing that . . . . That's the big issue. How can you engineer a system you don't fully understand?"

The actual effects of Mount Pinatubo were, in fact, complex. Climate models at the time predicted that by decreasing the amount of sunlight hitting the surface of the earth, the haze of sulfates produced in such an eruption would reduce evaporation, which in turn would lower the amount of precipitation worldwide. Rainfall did decrease—but by much more than scientists had expected. "The year following Mount Pinatubo had by far the lowest amount of rainfall on record," says Kevin Trenberth, a senior scientist at the National Center for Atmospheric Research in Boulder, CO. "In fact, it was 50 percent lower than the previous low of any year." The effects, however, weren't uniform; in some places, precipitation actually increased. A human-engineered sulfate haze could have similarly unpredictable results, scientists warn.

Even in a best-case scenario, where side effects are small and manageable, cooling the planet by deflecting sunlight would not

reduce the carbon dioxide in the atmosphere, and elevated levels of that gas have consequences beyond raising the temperature. One is that the ocean absorbs more carbon dioxide and becomes more acidic as a result. That harms shellfish and some forms of plankton, a key source of food for fish and whales. The fishing industry could be devastated. What's more, carbon dioxide levels will continue to rise if we don't address them directly, so any sunlight-reducing technology would have to be continually ratcheted up to compensate for their warming effects.

And if the geoengineering had to stop—say, for environmental or economic reasons—the higher levels of greenhouse gases would cause an abrupt warm-up. "Even if the geoengineering worked perfectly," says Raymond Pierrehumbert, a professor of geophysical sciences at the University of Chicago, "you're still in the situation where the whole planet is just one global war or depression away from being hit with maybe a hundred years' worth of global warming in under a decade, which is certainly catastrophic. Geoengineering, if it were carried out, would put the earth in an extremely precarious state."

SMARTER SULFATES

Figuring out the consequences of various geoengineering plans and developing strategies to make them safer and more effective will take years, or even decades, of research. "For every dollar we spend figuring out how to actually do geoengineering," says Schrag, "we need to be spending 10 dollars learning what the impacts will be."

To begin with, scientists aren't even sure that sulfates delivered over the course of decades, rather than in one short volcanic blast, will work to cool the planet down. One key question is how microscopic particles interact in the stratosphere. It's possible that sulfate particles added repeatedly to the same area over time would clump together. If that happened, the particles could start to interact with longer-wave radiation than just the wavelengths of electromagnetic energy in visible light. This would trap some of the heat that naturally escapes into space, causing a net heating effect rather than a cooling effect. Or the larger particles could fall out of the sky before they had a chance to deflect the sun's heat. To study such phenomena, David Keith, the director of the Energy and Environmental Systems Group at the University of Calgary, envisions experiments in which a plane would spray a gas at low vapor pressure over an area of 100 square kilometers. The gas would condense into particles in the stratosphere, and the plane would fly back through the particle cloud to take measurements. Systematically altering the size of the particles, the quantity of particles in a given area, the timing of their release, and other variables could reveal key details about their microscale interactions.

Yet even if the behavior of sulfate particles can be understood and managed, it's far from clear how injecting them into the stratosphere would affect vast, complex climate systems. So far, most models have been crude; only recently, for example, did they start taking into account the movement of ice and ocean currents. Sulfates would cool the planet during the day, but they'd make no difference when the sun isn't shining. As a result, nights would probably be warmer relative to days, but scientists have done little to model this effect and study how it could affect ecosystems. "Similarly, you could affect the seasons," Schrag says: the sulfates would lower temperatures less during the winter (when there's less daylight) and more during the summer. And scientists have done little to understand how stratospheric circulation patterns would change with the addition of sulfates, or precisely how any of these things could affect where and when we might experience droughts, floods, and other disasters.

If scientists could learn more about the effects of sulfates in the stratosphere, it could raise the intriguing possibility of "smart" geoengineering, Schrag says. Volcanic eruptions are crude tools, releasing a lot of sulfur in the course of a few days, and all from one location. But geoengineers could choose exactly where to send sulfates into the stratosphere, as well as when and how fast.

"So far we're thinking about a very simplistic thing," Schrag says. "We're talking about injecting stuff in the stratosphere in a uniform way." The effects that have been predicted so far, however, aren't evenly distributed. Changes in evaporation, for example, could be devastating if they caused droughts on land, but if less rain falls over the ocean, it's not such a big deal. By taking advantage of stratospheric circulation patterns and seasonal variations in weather, it might be possible to limit the most damaging consequences. "You can pulse injections," he says. "You could build smart systems that might cancel out some of those negative effects."

Rather than intentionally polluting the stratosphere, a different and potentially less risky approach to geoengineering is to pull carbon dioxide out of the air. But the necessary technology would be challenging to develop and put in place on large scale.

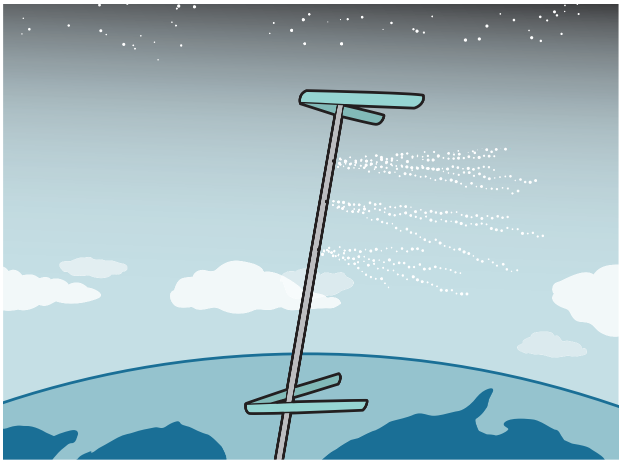
In his 10th-floor lab in the Manhattan neighborhood of Morningside Heights, Klaus Lackner, a professor of geophysics in the Department of Earth and Environmental Engineering at Columbia University, is experimenting with a material that chemically binds to carbon dioxide in the air and then, when doused in water, releases the gas in a concentrated form that can easily be captured. The work is at an early stage. Lackner's carbon-capture devices look like misshapen test-tube brushes; they have to be hand dipped in water, and it's hard to quickly seal them into the improvised chamber used to measure the carbon dioxide they release. But he envisions automated systems—millions of them, each the size of a small cabin—scattered over the countryside near geologic reservoirs that could store the gases they capture. A system based on

WWW

Scientists explain different geoengineering methods:
www.technologyreview.com/geoengineering

FIVE GEOENGINEERING SCHEMES

Researchers and entrepreneurs have proposed approaches ranging from the relatively cheap and simple to the elaborate. Here are the ones that have received the most attention so far.

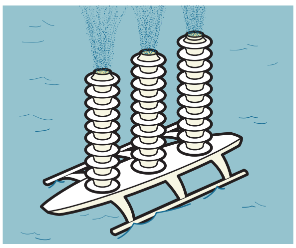


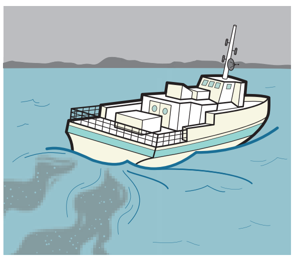
SULFATE INJECTION

Aircraft, or a hose suspended by hundreds of wing-shaped balloons, could inject aerosols into the upper atmosphere. The particles would reflect light and shade the earth.
Pros: It could be cheap and fast-acting, cooling the earth in months.
Cons: It could cause droughts. Injections might need to continue for hundreds of years.

CLOUD BRIGHTENING

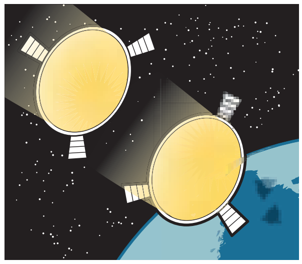
Tiny droplets made by spraying an extremely fine mist of seawater into low-lying clouds could make them reflect more sunlight than ordinary clouds.
Pros: Shading could be targeted—to stop the melting of Arctic Sea ice, for example.
Cons: Scientists don't know how it would affect precipitation and temperatures over land, where it would matter most.





OCEAN FERTILIZATION

Adding iron or other nutrients to the ocean could promote algae blooms, which would capture carbon dioxide and store some of it deep in the ocean.
Pros: It would directly address the root of climate change: carbon dioxide in the atmosphere.
Cons: At best, it could offset an eighth of the greenhouse-gas emissions attributed to humans, and it could harm ecosystems.

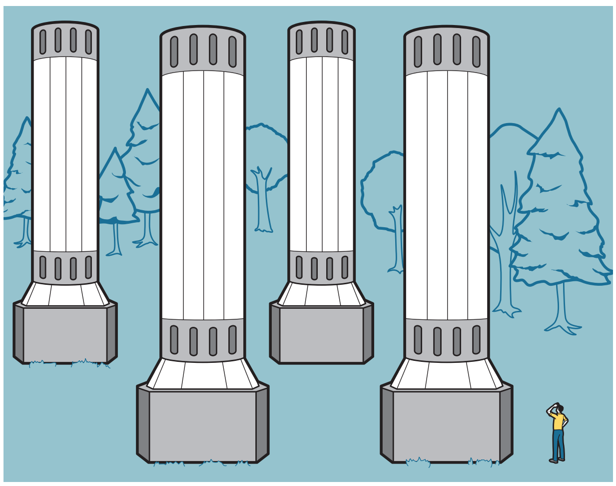


SPACE SHADES

Trillions of disks launched into space could reflect incoming sunlight.
Pros: Space-based systems don't pollute the atmosphere. Once in place, they would cool the earth quickly.
Cons: The technology could take decades to develop. And launching trillions of disks is fantastically expensive.

ARTIFICIAL TREES

Various chemical reactions can be used to capture carbon dioxide from the atmosphere for permanent storage.
Pros: In the long run, this could reduce atmospheric concentrations of carbon dioxide. There is no obvious limit to how much of the greenhouse gas could be stored.
Cons: It could be very expensive and energy intensive, and it would take a long time to reduce temperatures.



BROWN BIRD DESIGN

this material, he calculates, could remove carbon dioxide from the air a thousand times as fast as trees do now. Others at Columbia are working on ways to exploit the fact that peridotite rock reacts with carbon dioxide to form magnesium carbonate and other minerals, removing the greenhouse gas from the atmosphere. The researchers hope to speed up these natural reactions.

It's far from clear that these ideas for capturing carbon will be practical. Some may even require so much energy that they create a net increase in carbon dioxide. "But even if it takes us a hundred years to learn how to do it," Pierrehumbert says, "it's still useful, because CO_2 naturally takes a thousand years to get out of the atmosphere."

THE SEEDS OF WAR

Several existing geoengineering schemes, though, could be attempted relatively cheaply and easily. And even if no one knows whether they would be safe or effective, that doesn't mean they won't be tried.

David Victor, the director of the Laboratory on International Law and Regulation at the University of California, San Diego, sees two scenarios in which it might happen. First, "the desperate Hail Mary pass": "A country quite vulnerable to changing climate is desperate to alter outcomes and sees that efforts to cut emissions are not bearing fruit. Crude geoengineering schemes could be very inexpensive, and thus this option might even be available to a Trinidad or Bangladesh—the former rich in gas exports and quite vulnerable, and the latter poor but large enough that it might do something seen as essential for survival." And second, "the Soviet-style arrogant engineering scenario": "A country run by engineers and not overly exposed to public opinion or to dissenting voices undertakes geoengineering as a national mission—much like massive building of poorly designed nuclear reactors, river diversion projects, resettlement of populations, and other national missions that are hard to pursue when the public is informed, responsive, and in power." In either case, a single country acting alone could influence the climate of the entire world.

How would the world react? In extreme cases, Victor says, it could lead to war. Some countries might object to cooling the earth, especially if higher temperatures have brought them advantages such as longer growing seasons and milder winters. And if geoengineering decreases rainfall, countries that have experienced droughts due to global warming could suffer even more.

No current international laws or agreements would clearly prevent a country from unilaterally starting a geoengineering project. And too little is known now for a governing body such as the United Nations to establish sound regulations—regulations that might in any case be ignored by a country set on trying to save itself from a climate disaster. Victor says the best hope is for leading scientists around the world to collaborate on establishing as clearly as possible what dangers could be involved in geoengineering and how, if at all, it might be used. Through open international research, he says, we can "increase the odds—not to 100 percent—that responsible norms would emerge."

READY OR NOT

In 2006, Paul Crutzen, the Dutch scientist who won the Nobel Prize in chemistry for his discoveries about the depletion of the stratospheric ozone layer, wrote an essay in the journal *Climatic Change* in which he declared that efforts to reduce greenhouse-gas emissions "have been grossly unsuccessful." He called for increased research into the "feasibility and environmental consequences of climate engineering," even though he acknowledged that injecting sulfates into the stratosphere could damage the ozone layer and cause large, unpredictable side effects. Despite these dangers, he said, climatic engineering could ultimately be "the only option available to rapidly reduce temperature rises."

At the time, Crutzen's essay was controversial, and many scientists called it irresponsible. But since then it has served to bring geoengineering into the open, says David Keith, who started studying the subject in 1989. After a scientist of Crutzen's credentials, who understood the stratosphere as well as anyone, came out in favor of studying sulfate injection as a way to cool the earth, many other scientists were willing to start talking about it.

Among the most recent converts is David Battisti, a professor of atmospheric sciences at the University of Washington. One problem in particular worries him. Studies of heat waves show that crop yields drop off sharply when temperatures rise 3 °C to 4 °C above normal—the temperatures that MIT's Prinn predicts we might reach even with strict emissions controls. Speaking at a geoengineering symposium at MIT this fall, Battisti said, "By the end of the century, just due to temperature alone, we're looking at a 30 to 40 percent reduction in [crop] yields, while in the next 50 years demand for food is expected to more than double."

Battisti is well aware of the uncertainties that surround geoengineering. According to research he's conducted recently, the first computer models that tried to show how shading the earth would affect climate were off by 2 °C to 3 °C in predictions of regional temperature change and by as much as 40 percent in predictions of regional rainfall. But with a billion people already malnourished, and billions more who could go hungry if global warming disrupts agriculture, Battisti has reluctantly conceded that we may need to consider "a climate-engineering patch." Better data and better models will help clarify the effects of geoengineering. "Give us 30 or 40 years and we'll be there," he said at the MIT symposium. "But in 30 to 40 years, at the level we're increasing CO_2, we're going to need this, whether we're ready or not." TR

KEVIN BULLIS IS *TECHNOLOGY REVIEW*'S ENERGY EDITOR.

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project: Zipcar.com Redesign
agency/creator: Zipcar in partnership with ISITE Design

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project: Stanley Level iPhone App
agency/creator: Mullen with Aurnhamer LLC, for Stanley Works

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project: Happiness Factory 3
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Contributors

Corey Machanic
massAV

Medicine Meets Simulation

A distracted driver accelerates through a stop sign, knocking a rider off his bike. Soon an ambulance blares onto the scene. Medics rush out, check the man's vital signs, and intubate him to allow him to breathe. They load him onto a stretcher and transport him to a nearby medical facility, where the doctors immediately get to work.

The patient may survive. Or not. Even if he doesn't the medical team can review what they did wrong and try again, this time perhaps saving his life. Because this

patient is not alive. He's a simulation.

Until recently, doctors mostly trained by first watching procedures, then practicing them directly on patients. Researchers estimate that deaths from medical errors range between 44,000 and 98,000 every year. Nearly one million additional injuries are also attributed to medical error. "So you don't want to be the first one that the doctor or nurse works on," says John Anton, founder of the Florida-based simulation company Information Visualization and Innovative Research (IVIR). "Give them the opportunity to repeat situations they're going to have to face—that's what simulation is all about."

Once, doctors might have used a hard plastic figure to stand in for a patient. Today's mannequins simulate breathing, exhibit a pulse and mimic other vital signs, and can even "respond" to treatments. They offer a safe way for medical students, nurses, and emergency medical technicians (EMTs) to get their hands on patients and practice procedures over and over, literally gaining a realistic feel for applying lifesaving methods before they ever come in contact with a suffering human being.

Mannequins Come to Life

A major breakthrough in medical simulation took place more than 40 years ago, when Michael Gordon of the University of Miami invented a mannequin that he named Harvey, after an honored professor. Harvey could embody a number of the different cardiac diseases a doctor might confront; and depending on the disease, a stethoscope to the chest encountered any one of a number of different heart sounds. Transformative changes in technology have resulted in the latest versions of Harvey, who can now mimic dozens of cardiac and lung diseases with all their appropriate rushes and gurgles.

In 1996, Medical Education Technologies, Inc. (METI), based in Florida, began selling the first whole-body human simulators. Instead of lifeless, immobile mannequins, these models intricately mimic human physiology, with palpable pulses, discernable breathing, and the ability to talk and to respond to treatments. The "patient" can be programmed for any type of physiology and disease. According to Lou Oberndorf, CEO of METI, "It opened up an enormous number of possibilities in the ways to teach."

Today's simulators take advantage of the latest technology to go beyond simulating the vital signs and responses of diseases. The latest versions are plumbed to excrete from every orifice: they spurt blood at the site of a severed artery, and clear liquid streams from their eyes and noses to mimic the effects of a biological attack.

Beth Pettitt, division chief of the Soldier Simulation Environments at the Army's Simulation and Training Technology Center, explains that her office has challenged in-house and contract researchers to "come up with better representations of skin, bone, blood—so these wounds look right, smell right, feel right, and behave with physiological accuracy. Soldiers have to control bleeding, put a tourniquet on, and use a clotting agent if appropriate."

Download the *Medicine Meets Simulation White Paper* to learn more about

- increasingly realistic simulators;
- the military's use of medical simulation; and
- new tools to treat disorders such as PTSD and anxiety.

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BRIEFING MEDIA

Online delivery is putting new technology at the heart of media companies

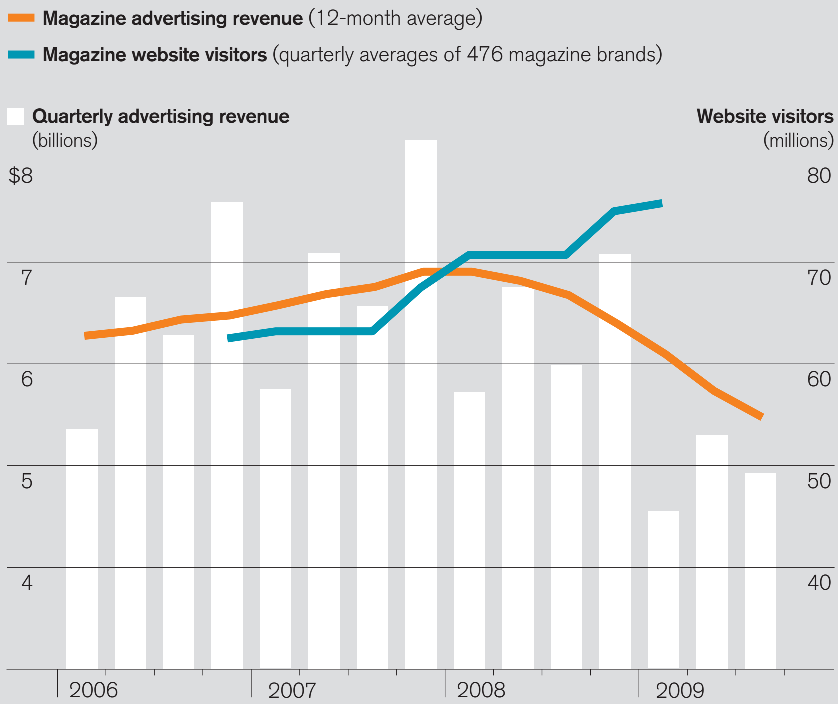
Traditional media supported themselves for decades by acting as brokers between advertisers and audiences. Audiences wanted content, and advertisers wanted access to audiences, so advertisers subsidized the bill for content. Now, cheap computing and network connectivity have created publishing platforms and advertising markets where advertisers and audiences no longer depend on media companies *(see "Convergence Is King," p. 66, and "Mainstream News Taps Into Citizen Journalism," p. 62).*

The media companies that look most likely to survive are those whose use of new technologies both attracts revenue directly from their audience (by adding value to content) and convinces advertisers that it makes sense to buy ad space from them. It's a tough challenge: people are used to getting news and entertainment free. But video-streaming websites like Netflix, and digital music stores like iTunes, have demonstrated that customers can be persuaded to pay for content.

Ad revenue will still be vital to many companies, but advertisers are reluctant to pay for online advertising beyond keyword-based systems, which typically cost money only once an ad is clicked. Advertisers were willing to pay for, say, expensive display ads in magazines because a lot of information was available about the magazine's readers and the effectiveness of such campaigns. By contrast, little is reliably known about online audiences. Technology that allows these audiences to be tracked and measured with precision will be essential to convincing advertisers to pay for online display advertising *(see "Bringing Advertisers Back," p. 61).*

It will be years before the media industry stabilizes. But it is clear that the surviving companies will be those that can give consumers the content they want, when they want it. This will require embracing technologies that work with whatever platform the consumer prefers—be it a Web browser, an Internet-connected television, or a smart phone *(see "Media Moves Online," p. 60)*—and can give advertisers confidence that they are getting value for money. *—Stephen Cass*

UPS AND DOWNS
Online readership is growing, but magazines are pulling in less money



Source: Magazine Publishers Association, Nielsen Online

CHARTS BY TOMMY McCALL

DAVID SACKS/GETTY IMAGES

TECHNOLOGY OVERVIEW

Media Moves Online

Technology has torn down the walls between different communications media. Magazines produce video clips, while television news stations post written articles online. The technologies that are driving this media convergence are network connections, powerful mobile devices, clever interfaces, and easy-to-use software.

One of the most visible manifestations of the new technology is the rise of "we media," or citizen journalism, which enables all kinds of people to post anything they want online *(see "Mainstream News Taps Into Citizen Journalism," p. 62)*. Several companies, including TypePad, WordPress, and Vox, offer blog platforms that can be used as is or customized with plug-in software to support sophisticated media sites. Sites like YouTube and Blip.tv similarly make it easy to share video content.

Book publishers, meanwhile, are seeing a boom in electronic readers, thanks in large part to the display technology made by E Ink of Cambridge, MA *(see "Companies to Watch," p. 67)*. Its electronic ink is used in all the major e-readers, including Amazon's Kindle and the Sony Reader. Though they are using similar display technologies, e-book makers are looking to distinguish their products by adding new features: support for audio books or other types of media, for example, or digital rights management that allows users to loan e-books to friends. These dedicated e-readers are expected to face more competition from new smart phones, which offer touch-screen interfaces and large catalogues of third-party applications.

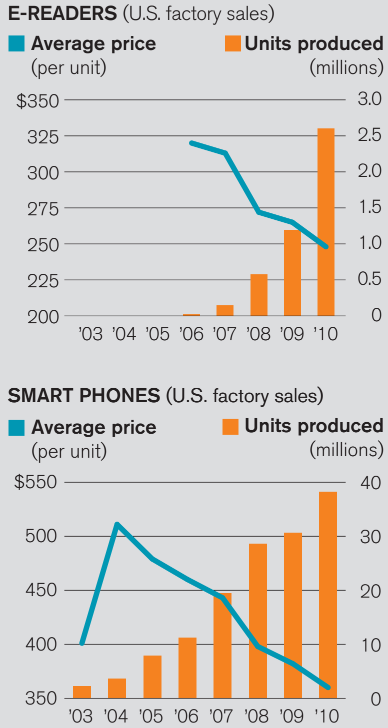
Smart phones are also becoming devices for watching video, thanks to technologies such as variable-bit-rate compression. This compression technology, which reduces the size of video files by using more data for complex segments of audio or video and less for simpler content, enables high-quality video to come through smoothly even with limited bandwidth. Compressed video streamed over the Internet through sites such as Hulu and Netflix is now a viable alternative to DVD players and cable television, and new television sets such as the Sony Bravia can play video directly from Internet feeds. Startups such as Boxee have created software that makes it easier for users to play and share personal and Internet media on a television.

Ashley Still, group product manager of Flash media distribution at Adobe Systems, says that as new protocols make the Internet faster at handling video content, a software video player or television can increasingly become "more than just a dumb

Take a snapshot of this code to read a special report on smarter IT. For the software, visit www.neoreader.com.

HANDHELD HEAVEN

Mobile media devices are flying off the shelves



Source: Consumer Electronics Association

rectangle playing back content." Thanks to the new protocols, interactive applications can stream as well. OnLive, for example, is streaming high-performance video games to users over the Internet—something that was previously unheard of, because delays would have ruined the game experience.

Easy digital distribution has also detached content from its source. Internet protocols such as Really Simple Syndication (RSS) allow users to automatically gather items of interest from websites whenever they're updated, in some cases reading or viewing them on a secondary site rather than visiting the original. Experts are working on new protocols that will deliver these updates faster. To deter piracy and gather audience statistics for advertising purposes *(see "Bringing Advertisers Back," right)*, new tools have been developed to track where people are talking about or consuming a piece of content.

Some media companies are embracing this distribution model by making it even easier to spread articles or videos around. They are creating application program interfaces, or APIs, that allow third-party developers to access their content and use it for products such as smart-phone applications, and media companies themselves are using APIs provided by social-networking sites such as Facebook to publish content on those sites.

The combined effect of these technologies will be to bring new media together into a "real-time Web." In this new environment, any piece of content produced will be discovered and discussed online almost instantaneously. —*Erica Naone*

DATA SHOT

23.8 million

The number of U.S. cellular subscribers with touch-screen smart phones—a 159 percent rise over the previous year, according to ComScore.

INDUSTRY CHALLENGES

Bringing Advertisers Back

Online, advertisers are spending a small fraction of what they used to spend for space in traditional media. This presents a big problem for media companies. Although they save money by distributing their products over the Internet, they still incur sizable fixed costs to create content. How can these companies make money?

Possible answers are to rely more on revenue from subscriptions and direct sales *(see "Convergence Is King," p. 66)* or to shift to a nonprofit model supported by grants and donations. But these strategies alone rarely close the finance gap. Most media companies must convince advertisers that the online display advertising they sell—the banners, boxes, and so on—is worth more than advertisers currently think.

The research firm eMarketer estimates that in 2009, advertisers spent $22.4 billion online in the United States. Unfortunately for publishers, "keyword" or search advertising—the links sold by Google and other search engines—is taking an ever larger portion of that money, squeezing out display ads. In 2008, search advertising grew 25 percent, while display grew only 9 percent. Advertisers are reluctant to pay for display ads because of limits on how well audiences and their behavior can be tracked online. Traditionally, broadcast and print companies provided detailed and trusted information about the size and demographic makeup of their audiences. But no existing information source has succeeded in giving advertisers the confidence to increase their investment in online advertising, says Paula Storti, founder of Worldwalk Media, a global marketing and advertising agency.

An accurate count of a website's audience is essential, since advertisers will pay more if 10 different people view an ad than if one user views the ad 10 times. Two main methods dominate online audience measure-

A few of the well-known magazines shuttered because of falling advertising revenues

ment. The first is analysis of cookies stored on visitors' browsers and in publishers' "log files"—a history of Web page requests. The second relies on audience profiling using panels of consumers. There is no consensus on which gives advertisers a better picture of a website's audience. Companies that rely on cookies and log-file analysis, such as Omniture (recently acquired by Adobe), WebTrends, and Coremetrics, provide very limited demographic information and are frequently accused of overcounting audience size because of factors such as individuals who use multiple computers and privacy software that automatically deletes cookies. Panel-based metrics companies such as ComScore and Nielsen Online recruit Web users to answer detailed demographic surveys and have their browsing monitored by software installed on their home computers. Panels provide the demographic information that ad buyers are accustomed to getting from media such as magazines and television, but the method undercounts websites' audiences, especially when visitors browse from work. In particular, panels often grossly underestimate the audiences of smaller sites.

Web analytics companies are now seeking to correct for undercounting by incorporating audience profiles into log-file analyses or statistical models of overall Internet traffic *(see "But Who's Counting?" March/April 2009 and at technologyreview.com).* San Francisco startup Quantcast is perhaps the farthest down this path, combining log-based measurement with demographic information from market research firms and Internet service providers *(see "Companies to Watch," p. 67).*

The growth of the mobile Internet—with its diversity of technologies, devices, communication protocols, operating systems, and systems for supporting images, cookies, and JavaScript—further complicates audience measurement. Startups such as Mobilytics, Bango, AdMob (recently purchased by Google), Localytics, and Motally have developed software tags that publishers can build into their websites and mobile apps to track audiences. Only one thing is for sure: if media companies want to stay in business, they'd better find a solution that advertisers like—fast. *—Erika Jonietz*


Iranians used social-networking sites to report on the suppression of street protests.

AHMAD ABBAS/GETTY IMAGES

WE MEDIA

Mainstream News Taps Into Citizen Journalism

Last June, a disputed presidential election sparked a wave of unrest in Iran. The government blocked foreign and domestic news services from covering events, but Iranians used social-networking websites to bypass the censors. Eyewitness accounts of the bloody suppression of protests were sent out minute by minute. When a bystander named Neda Agha-Soltan was shot to death, harrowing footage was captured by cell-phone camera and posted to Facebook.

The coverage of the Iranian election protests was an example of "we media," a term that encompasses a wide range of mostly amateur activities—including blogging and commentary in online forums—that have been made possible by an array of technologies. There are probably hundreds of millions of active blogs worldwide, though no one has made a definitive count. Social-networking sites like Facebook and Twitter, too, become media platforms when news is propagated through status updates and 140-character tweets that can easily be transmitted to smart phones.

Some enthusiasts believe that such media will render traditional news outlets obsolete. They will always have a superior geographic range, since Internet and cell-phone connections are available in most of the world. They can connect readers directly to sources and documentation without any filtering: celebrities, politicians, and scientists alike now maintain a presence online. Low-cost consumer hardware and free software make it practical to cover

subjects whose audiences are too small to support professional journalists.

A more likely scenario, however, is coexistence, or even a symbiotic relationship. Mainstream media websites still draw hundreds of millions of visitors each month *(see "Convergence Is King," p. 66)*. In large part this is because media organizations assign stories to journalists—who should be better informed and more articulate than the average blogger if they want to get paid—rather than just hoping that a motivated citizen is following a trend or has happened to get close to an event. And if the strength of "we media" comes from the power of the unfiltered individual, a strength of traditional media organizations is that they bring together teams to create coördinated packages of text, photography, illustration, audio, and video. These organizations, which rely heavily on reputation to distinguish themselves in the market, are also accountable in a way that often anonymous citizen journalists are not.

Citizen journalists and online commenters rely on media organizations for reliable information, while organized media looks to them to drive traffic and occasionally break news. Some media organizations have already tried to reach out: the BBC and CNN, for example, have created systems that allow viewers to submit digital pictures, messages, or videos during major news events. YouTube Direct, a new service from Google, will allow any media organization to set up a similar system. Users can upload a video to YouTube via the media organization's website, and if it's approved, it is incorporated into the organization's coverage and tagged on the YouTube site with the organization's URL. Media organizations have also begun paying professional journalists to run neighborhood blogs. Typically, these hyperlocal news sites are run by amateurs today. But they are frequently abandoned after a year or two as the bloggers get busy with work and other demands on their time—suggesting that someone whose work *is* journalism still has a role to play. —*Stephen Cass*

DATA SHOT

14,689

At press time, the approximate number of layoffs and buyouts at U.S. newspapers in 2009, as reported by the blog Paper Cuts.

CASE STUDY

Patrolling the Web for Pirated Content

Piracy of copyrighted work is rampant on the Internet. The plague of "scraper sites" is just one example: they copy content belonging to other sites in hopes of snagging readers—and advertising revenue from automated networks such as Google's AdSense.

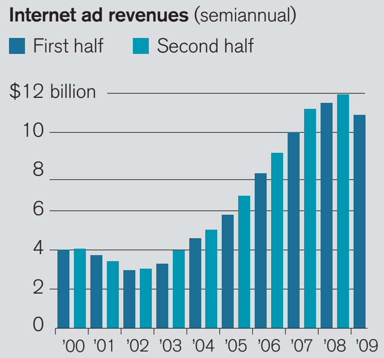
In the United States, the Digital Millennium Copyright Act (DMCA) lets copyright holders protect themselves by sending online service providers a "takedown notice" if one of the providers' users uploads content belonging to the rights holder. Removing offending material immunizes providers from being sued as accomplices to intellectual piracy. (Similar laws exist in most of the developed world.) Search engines can also be ordered to remove links to such content from search results.

The problem for copyright holders is that before they can serve notice, they must first spot the unauthorized copies of their content. Attributor, a company based in Redwood City, CA, was founded in 2005 to turn this problem into money. "People give us their content. We then crawl the Internet and find where and how it's being reused," says Jim Pitkow, who cofounded Attributor and serves as its CEO.

While the system can detect partial copies—the initial scan can spot as little

BOOMING BUSINESS

Despite a recent dip in revenue, online ad campaigns are still popular with advertisers



Source: Interactive Advertising Bureau

DATA SHOT

18%

The portion of global Internet traffic generated by peer-to-peer file sharing, according to the Atlas Internet Observatory. Much, if not most, of this traffic comes from illegally sharing copies of music, games, TV shows, and movies. Peer-to-peer traffic is declining in favor of new streaming-video services, which are typically legal.

as two or three sentences of a client's content embedded in a Web page, according to Pitkow—Attributor is focusing on complete or nearly complete copies that reuse more than 125 words. This avoids the thorny issue of determining what is and isn't covered by the "fair use" exemption in copyright law, which allows people to incorporate portions of a copyrighted work for the purposes of commentary, education, or parody. Once matches are found, Attributor can respond on behalf of its clients.

Even when complete copies are found, sending a takedown notice tends to be a last resort; the tactic is often perceived as corporate bullying. Instead, a publisher might, for example, ask a blogger reposting a news story to provide appropriate attribution and add a link back to the originating website.

Ultimately, Attributor hopes its tracking data will be used in a system where online advertising networks agree to give its clients a share of any ad revenue from pages that contain copied content or face a torrent of takedown notices under the DMCA. So far the networks have been cool to this idea. In the meantime, media clients, which include CondéNet, Thomson Reuters, and the Associated Press, find Attributor's service valuable for tracking where their content is appearing: a site that frequently uses a publisher's content might be amenable to striking a licensing deal, converting a pirate into a customer.
—*Stephen Cass*

ASIA-PACIFIC

Diverse Technologies Flourish in Fragmented Markets

In June 2008, there were 253 million Chinese Internet users. Twelve months later, there were 338 million. South Korea is planning to roll out one-gigabit broadband connections nationwide by 2012, and Japan leads the world in mobile telecommunications, with high-bandwidth 4G cellphone service expected to be available later this year.

This audience represents a huge opportunity for digital-media entrepreneurs. But the Asia-Pacific region is a mosaic of disparate societies that leave the market fragmented between countries and even within them.

In China, discussion boards dominate; in South Korea, Internet gaming is huge; in Australia, Western social-media sites like Facebook are popular. Western companies going into countries such as South Korea and China "have found it a terrible struggle to find any success," says Michael Netzley, a professor of corporate communication at Singapore Management University. "It's so incredibly diverse that you must localize your activities." Among foreign entrants to the Chinese market, Google has probably had the best results: it has gained about 31 percent of the market by doing things like creating a specialized music search service that makes it easy to find legal MP3s (downloading music is a major preoccupation of Chinese users) and—controversially—self-censoring search results to avoid running afoul of the "Great Firewall of China," which can block traffic deemed offensive to the government. But it lags well behind the Beijing-based Baidu *(see Companies to Watch, p. 67)*, which commands

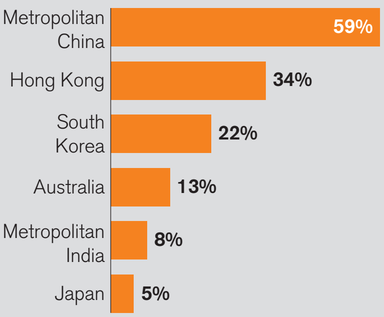
Many people in China use Internet cafés like this one to go online.

DB IMAGES/ALAMY

DIFFERENT STROKES

The appeal of an online activity can vary widely across the Asia-Pacific region

Percentage of people who watch full-length TV shows on Internet sites (at least monthly)



Source: Asia Pacific Technographics Survey, Q2 2009

about 64 percent of the Chinese search-engine market by offering a wide range of services closely matched to the needs of Chinese users, including a popular online encyclopedia and an e-commerce platform.

Despite Baidu's dominance in China, however, that company has little presence elsewhere in the region (though it's currently trying to make inroads into Japan), demonstrating the tradeoffs a company makes if it's perfectly in sync with the local zeitgeist. Would-be competitors are stymied, but at the same time, says Netzley, "companies that have tried to export their local success have failed miserably." —*Stephen Cass*

DATA SHOT

46%

Portion of the 338 million Chinese users who were accessing the Internet from mobile phones in June 2009, up from 39.5 percent six months previously. Many mobile users also access the Internet over desktop and laptop computers.

Vint Cerf was among industry leaders testifying at a June 2006 Senate hearing on communications laws.

CONGRESSIONAL QUARTERLY/GETTY IMAGES

POLICY

Battling over Neutrality

The U.S. Federal Communications Commission (FCC) issued its draft of proposed "net neutrality" regulations in October. These rules would require Internet service providers to handle all data the same way, prohibiting them from slowing down or blocking access to specific websites or applications. Cable companies would be unable to limit video streaming from a site like Netflix; telephone companies couldn't choke voice-over-IP services like Skype. A vote by the commission is expected by fall 2010.

Some critics of net neutrality claim that it could reduce quality of service, especially if it is applied to mobile operators, who are already struggling to control congestion caused by bandwidth-hogging smart phones.

Attempts to guarantee net neutrality through federal legislation failed in 2006 and again in 2007. The FCC believes it has the authority to introduce net neutrality rules under its existing mandate, but Senator John McCain has moved to block the commission by introducing the Internet Freedom Act, legislation that would expressly prohibit it from making such rules.

Even if that legislation fails, net neutrality faces a legal challenge: Comcast is already fighting the FCC in court over similar guidelines that the commission issued in 2004. In 2008, the commission sanctioned Comcast for blocking peer-to-peer traffic, and the company is appealing that decision. A win by Comcast could negate all or part of any net neutrality regulations the FCC might enact. — *Erika Jonietz*

Rupert Murdoch addresses the *Wall Street Journal* newsroom after acquiring the paper in 2007.

MARKETWATCH

Convergence Is King

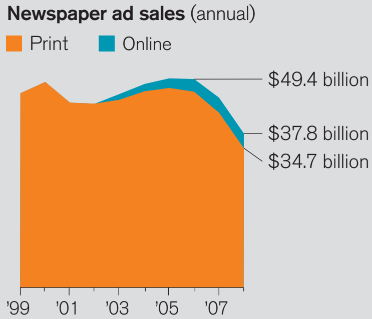
It's not hard to name the biggest losers in today's media landscape: newspapers. In 2009, more than 130 U.S. newspapers either closed or moved to online-only publication, typically with skeleton staffs. The big-city daily papers that once defined American journalism have seen their business model collapse as Internet-based competitors commodified news and slashed the cost of advertising.

Newspapers have no problem attracting readers online; the Newspaper Association of America reports that its members' websites draw 74 million unique visitors per month. The problem is figuring out how to make money. Many publishers, of course, would like to start charging for content. But publishers "aren't talking about what kind of [additional] value they are going to give their customers or how they are going to use technology in an innovative way," says Robert Picard, a professor of media economics at Jonkoping University in Sweden and the editor of the *Journal of Media Business Studies*.

Dow Jones has been able to charge online for the *Wall Street Journal*, because its specialized content is not easily found elsewhere. Similarly, Bloomberg manages to charge premium prices for business news and information. This suggests an approach for struggling newspapers: by developing niche coverage, such as in-depth reporting on a sports team or a particular industry, they can offer content that is hard to duplicate. Online, such content may also find a wider audience than the local readers that newspapers traditionally served. Earlier attempts at charging for such products failed, probably because of the high prices publishers set. Last September, in a lower-priced experiment with this kind of strategy, the Minneapolis *Star Tribune* launched a premium website centered on the Vikings football team; three months' access costs $5.95.

PAPER LOSSES

Newspaper online ad sales bring in a fraction of what print sales did



Source: Newspaper Association of America

The key technical characteristic of what works is the ability to facilitate consumers' desire to read, watch, or listen to any content they want, anywhere, anytime. For print media, that makes it attractive to sell subscriptions on devices such as Amazon's Kindle and Barnes and Noble's Nook; 2.6 million e-readers are expected to be sold in the United States in 2010, more than twice as many as in 2009.

Beyond print, the many companies vying to put video on television screens are drawing investors' interest. Netflix, for example, has partnered with Roku to provide a set-top box for televisions that streams movies from Netflix's online catalogue; Microsoft and Sony are pushing their game consoles as on-demand media players; and Intel and Yahoo are collaborating on built-in software and chipsets that will enable televisions to run interactive applications.

Who is the king of new media? Apple. Despite the global economic meltdown, Apple has converted consumers' appetite for convergence into the biggest profits in the company's history, selling more than 33 million iPhones since the device's introduction in 2007—21 million in the 2009 fiscal year alone. In the new-media gold rush, it is selling the picks and shovels: its media business model, much like Google's, is dedicated to making it easier for users to enjoy other people's content. The iPhone represents just the latest advance in Apple's convergence strategy, which dates back to the 2001 launch of the iPod music player and 2003 launch of the iTunes music store. Defying the conventional wisdom that people won't pay for anything they can get online free, Apple can "deliver all kinds of content to you in a way that is so seamless that you cannot pass it up," says James McQuivey, an analyst with Forrester Research. "It's easier to buy media from iTunes than it is to steal it."

—*Stephen Cass*

MARK LENNIHAN/ASSOCIATED PRESS

MARKET TABLES

Companies to Watch

PUBLIC

Company	2008 R&D spending	
Amazon.com AMZN; Seattle, WA; founded 1994; 20,700 employees	$1.0 billion	Led the charge in bringing electronic books into the mainstream with its Kindle e-readers. Is facing challenges from competitors such as Sony and Barnes and Noble, which recently introduced its Nook e-reader.
Apple AAPL; Cupertino, CA; founded 1976; 36,800 employees	$1.1 billion	Its iPhone and iPod devices, coupled with its iTunes Music Store, reshaped the digital-media landscape. There are rumors that the company is developing a tablet computer with a large touch-screen interface that could let it enter the e-reader market.
Baidu BIDU; Beijing; founded 2000; 6,387 employees	$42.0 million	Commands about two-thirds of the booming Chinese search market after successfully holding off Google with a range of services attuned to local users. Whether it can compete on a global scale is uncertain.
ComScore SCOR; Reston, VA; founded 1999; 581 employees	$14.8 million	The current market leader in metrics, ComScore is attempting to reliably measure online audiences across multiple platforms, including the Web and mobile devices. Such measurement would provide a reliable way for marketers to decide how much to pay content providers for advertising. Competitors include Quantcast.
Google GOOG; Mountain View, CA; founded 1998; 19,655 employees	$2.8 billion	Google's advertising networks are what allow many online media creators to make some money from their content. Its ownership of YouTube gives the company a huge presence in online video, and its Android operating system may represent the only serious competition to the iPhone in the smart-phone market.
Netflix NFLX; Los Gatos, CA; founded 1997; 1,644 employees	$89.9 million	After disrupting the store-based model of Blockbuster and similar chains with its DVD-by-mail subscription service, Netflix has introduced a video-on-demand service on its website. It has also worked with manufacturers of televisions and set-top boxes to stream its catalogue directly to TV screens.
The New York Times Company NYT; New York City; founded 1896; 9,346 employees	not available	Once synonymous with American journalism, the company, which owns the *Boston Globe* and the *International Herald Tribune*, has struggled with the collapse of advertising in the newspaper industry. With more than 17 million unique Web visitors per month, it is experimenting with ways to make money online.
News Corp. NWSA; New York City; founded 1922; 55,000 employees	not available	Rupert Murdoch's multimedia empire develops virtually no technology itself. Nevertheless, it has mastered convergence, successfully selling intellectual property across multiple platforms and regions. Murdoch is also a strong proponent of paid content, charging for online access to the *Wall Street Journal* and threatening to opt out of Google's search index.
Sony SNE; Tokyo; founded 1946; 171,300 employees	$5.5 billion	Controls a huge amount of digital content but has made a number of missteps in dealing with media convergence; its slowness to develop on online service for its Playstation 3 console is just one example. However, Sony has moved quickly to bring new media devices to market, including e-readers and televisions that support Internet video.
Thomson Reuters TRI; New York City; founded 1851; 53,700 employees	not available	Has proved very willing to experiment with new technologies that will allow it to syndicate its news content online. Its financial-analytics services are facing new competition from Google and Yahoo, which are offering similar services at low or no cost.

PRIVATE

Company	Funding raised	
Amobee Redwood City, CA; founded 2005; 50-100 employees	$42 million	Offers software that allows telecom operators to insert text, graphic, and video advertisements into applications running on mobile devices such the iPhone and BlackBerry, creating a new revenue stream for operators and content providers.
Blip.tv New York City; founded 2005; 19 employees	over $8 million	Its platform allows the same content to be distributed automatically in multiple channels, including YouTube, iTunes, and Internet-enabled television. Advertisers can target viewers watching specific categories of content.
E Ink Cambridge, MA; founded 1997; 127 employees	over $150 million	Provides display technology for all the major e-readers, including those sold by Sony, Amazon, and Barnes and Noble. In the next two years, it is expected to face serious challenges from competitors such Plastic Logic and Pixel Qi, which use rival technologies. At press time, E Ink was merging with Prime View International, with the deal to be closed in December 2009.
Facebook Palo Alto, CA; founded 2004; over 900 employees	over $700 million	Runs the world's largest social-networking website, with more than 350 million active users. Facebook can host third-party applications and delivers targeted advertising. It is currently working to integrate its service into many different platforms, including gaming consoles and Internet-enabled television.
Hulu Los Angeles; founded 2007; 160 employees	over $100 million	Offers video content that can be streamed from its website, effectively competing with cable and satellite television providers. NBC Universal, News Corp., Walt Disney, and Providence Equity Partners each have a stake.
Innovid New York City; founded 2007; 15 employees	$3.8 million	Allows advertising to be incorporated into video content. The advertising is inserted at play time, allowing different audiences to be targeted with the same content. The incorporated material can also be interactive, potentially allowing viewers to purchase, for example, an item of clothing worn by an actor.
Mashery San Francisco, CA; founded 2006; 28 employees	$8.2 million	Provides infrastructure that helps media companies develop, publish, and manage application programming interfaces, or APIs, which allow outside developers to incorporate another company's content into their products.
Pixel Qi San Bruno, CA; founded 2008; number of employees not disclosed	not disclosed	Is developing a technology for low-power, low-cost displays that are readable in direct sunlight. The company is moving into mass production, with netbooks targeted as the first application for its 3Qi screen. E-readers could be next.
Quantcast San Francisco, CA; founded 2006; 70 employees	$25.7 million	Uses machine learning techniques to provide advertisers with detailed demographic information about online audiences. The company hopes to encourage media organizations to submit traffic data by offering basic services free.
Twitter San Francisco, CA; founded 2006; 83 employees	$155 million	Allows users to post 140-character messages. Twitter has become fertile ground for breaking news as interesting posts and links to external websites are rapidly reposted from user to user. The business model for sustaining the service remains unclear, perhaps even to Twitter.

Company information compiled by Amanda Peyton, Jimena Almendares, Jen Novak, and Rene Reinsberg.
For extended information about the public and private companies to watch, visit Technology Review *online at technologyreview.com/briefings/media/companies.*

MARKET TABLES

Research to Watch

Project	
Printcasting Participata www.printcasting.com	Supported by a $837,000 grant from the Knight News Foundation, Participata is testing a service that allows amateur publishers to create niche and local newsletters and magazines. Magazines are automatically generated from blogs and other online content chosen by the publisher; advertisements, typically from local retailers, are incorporated. Publishers can pay to have the magazine printed or offer it free online. Advertising revenues are shared by publishers, content creators, and Participata.
Ushahidi Engine Ushahidi www.ushahidi.com	Is developing an open-source platform that allows amateur and professional journalists to respond rapidly to regional crises. Users can file reports, which are plotted on an interactive map, by mobile phone, e-mail, or Web interface. Al Jazeera used the first generation of the Ushahidi Engine in its coverage of the Gaza war in January 2009, and activists used it to monitor federal elections in Mexico in July 2009.
Digital Preservation Europe A consortium of 11 European universities, libraries, and archives www.digitalpreservationeurope.eu	Much of the news coverage and entertainment created today is at risk of being lost within a few years because of changes in technology and the fragility of the storage medium. The consortium is working on methods to store digital media for future accessibility.
Peer-to-Peer Video Broadcast System Microsoft Research research.microsoft.com/en-us/projects/p2pbroadcast/	Transmitting live video streams to large audiences tends to overload the content provider's bandwidth. Under development is a system that solves the problem using peer-to-peer networks. A demonstration system was used to transmit live footage of the Beijing Olympics.
Google Listen Google listen.googlelabs.com	Using an interface based on the Android operating system, Google Listen is creating a search engine for audio podcasts. It will assemble podcasts matching a search term into a queue, creating a customized "audio magazine." Only English-language podcasts are currently indexed.
SixthSense MIT Media Lab www.pranavmistry.com/projects/sixthsense/index.htm	Is creating a wearable augmented-reality system that will overlay digital information onto physical objects around the user.
TV Everywhere Comcast, Time Warner	Is piloting a system that will allow cable subscribers to access programming on demand from anywhere with an Internet connection, possibly creating a strong competitor to video-streaming websites such as Hulu.
4G Cellular Network NTT DoCoMo www.nttdocomo.com/technologies/future/toward/index.html	4G mobile network technology is in its final stages of research and development; the company hopes the roll-out will occur later this year. The data rate should be between 100 megabits and one gigabit per second. (A typical DSL landline in the U.S. has a data rate of one to three megabits per second.) Such speeds would allow high-quality downloads of full-length movies in minutes.
High-Performance Video Coding Moving Picture Experts Group (MPEG) www.chiariglione.org/mpeg/	Aiming to improve video quality on everything from smart phones to giant televisions, the group is evaluating new coding and compression techniques. Previous technologies developed by the group now underlie most digital multimedia formats.
Advertising Works Yahoo Research research.yahoo.com/project/2616	Is attempting to track the effectiveness of online advertising campaigns—in particular, how they affect sales when the reader doesn't click on the ad.

REVIEWS

MICROFLUIDICS

Shoveling Water

WHY DOES IT TAKE SO LONG TO COMMERCIALIZE NEW TECHNOLOGIES?

By DAVID ROTMAN

The new microfluidic chip fabricated by Fluidigm, a startup based in South San Francisco, represents a decade of successive inventions. This small square of spongy polymer—the same type used in contact lenses and window caulking—holds a complex network of microscopic channels, pumps, and valves. Minute volumes of liquid from, say, a blood sample can flow through the maze of channels to be segregated by the valves and pumps into nearly 10,000 tiny chambers. In each chamber, nanoliters (billionths of a liter) of the liquid can be analyzed.

BIOMARK 96.96 DYNAMIC ARRAY
Fluidigm

THE NATURE OF TECHNOLOGY: WHAT IT IS AND HOW IT EVOLVES
by W. Brian Arthur
Free Press, 2009

The ability to move fluids around a chip on a microscopic scale is one of the most impressive achievements of biochemistry over the last 10 years. Microfluidic chips, which are now produced by a handful of startup companies and a similar number of university-based foundries, allow biologists and chemists to manipulate tiny amounts of fluid in a precise and highly automated way. The potential applications are numerous, including handheld devices to detect various diseases and machines that can rapidly analyze the content of a large number of individual cells (each holding about one picoliter of liquid) to identify, for example, rare and deadly cancerous mutations. But microfluidics also represents a fundamental breakthrough in how researchers can interact with the biological world. "Life is water flowing through pipes," says George Whitesides, a chemist at Harvard University who has invented much of the technology used in microfluidics. "If we're interested in life, we must be interested in fluids on small scales."

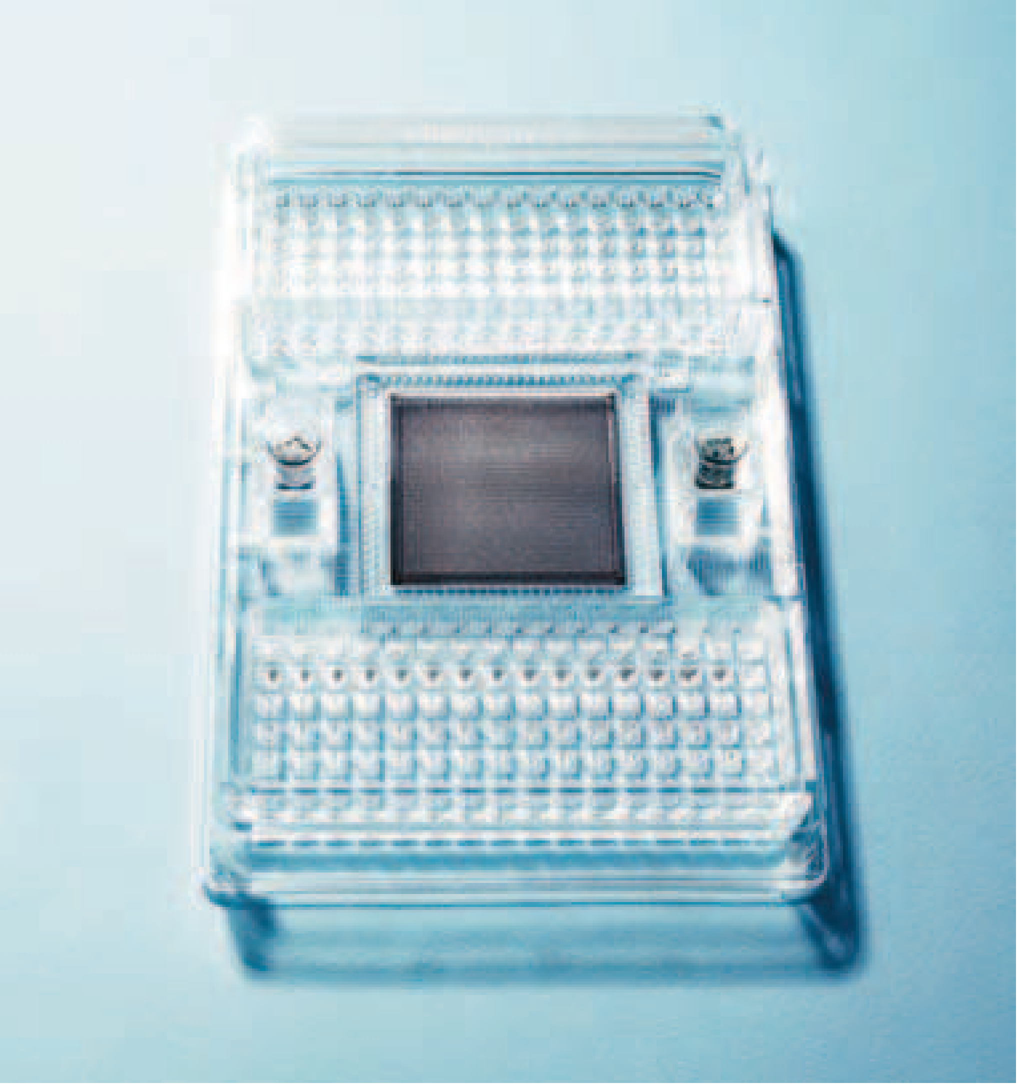
By way of explaining the importance of the technology and the complexity of its microscopic apparatus, those involved in microfluidics often make comparisons to microprocessors and integrated circuits. Indeed, a microfluidic chip and an electronic microprocessor have similar architectures, with valves replacing transistors and channels replacing wires. But manipulating liquids through channels is far more difficult than routing electrons around an integrated circuit. Fluids are, well, messy. They can be hard to move around, they often consist of a complex stew of ingredients, and they can stick and leak.

Over the last decade, researchers have overcome many such challenges. But if microfluidics is ever to become truly comparable to microelectronics, it will need to overcome a far more daunting challenge: the transition from promising laboratory tool to widely used commercial technology. Can it be turned into products that scientists, medical technicians, and physicians will want to use? Biologists are increasingly interested in using microfluidic systems, Whitesides says. But, he adds, "do you go into the lab and find these devices everywhere? The answer is no. What's interesting is that it hasn't really taken off. The question is, why not?"

A similar question could just as well be asked about at least two other important technologies that have emerged over the last decade: genomic-based medicine and nanotechnology. Each began this century with significant breakthroughs and much fanfare. The sequencing of the human genome was first announced in early 2001; the National Nanotechnology Initiative, which helped launch much of today's nanotech research, got its first federal funding in 2000. While all three technologies have produced a smattering of new products, none has had the transformative effects many experts expected. Why does it take so long for a technology as obviously important and valuable as these to make an impact? How do you create popular products out of radically new technologies? And how do you attract potential users?

PATIENCE, PATIENCE

Despite the economic, social, and scientific importance of technology, the process of creating it is poorly understood. In particular, researchers have largely overlooked the question of how technologies develop over



LAB ON A CHIP Fluidigm's microfluidic chip (the gray square in the center) uses tiny channels and valves to manipulate liquids. It allows fast and sensitive bioassays.

JOSHUA SCOTT

time. That's the starting point of W. Brian Arthur's *The Nature of Technology*, an attempt to develop a comprehensive theory of "what technology is and how it evolves." Arthur set to work in the library stacks at Stanford University. "As I began to read, I was astonished that some of the key questions had not been very deeply thought about," he recalled in a recent interview. While much has been written on the sociology of technology and engineering, and there's plenty on the histories of various technologies, he said, "there were big gaps in the literature. How does technology actually evolve? How do you define technology?"

Arthur hopes to do for technology what Thomas Kuhn famously did for science in his 1962 *The Structure of Scientific Revolutions,* which described how scientific breakthroughs come about and how they are adopted. A key part of Arthur's argument is that technology has its own characteristics and "nature," and that it has too long been treated as subservient to science or simply as "applied science." Science and technology are "completely interwoven" but different, he says: "Science is about understanding phenomena, whereas technology is really about harnessing and using phenomena. They build out of each other."

Arthur, a former professor of economics and population studies at Stanford who is now an external professor at the Santa Fe Institute and a visiting researcher at the Palo Alto Research Center, is perhaps best known for his work on complexity theory and for his analysis of increasing returns, which helped explain how one company comes to dominate the market for a new technology. Whether he fulfills his goal of formulating a rigorous theory of technology is debatable. The book does, however, offer a detailed description of the characteristics of technologies, peppered with interesting historical tidbits. And it provides a context in which to begin understanding the often laborious and lengthy processes by which technologies are commercially exploited.

Particularly valuable are Arthur's insights into how different "domains" of technology evolve differently compared to individual technologies. Domains, as Arthur defines them, are groups of technologies that fit together because they harness a common phenomenon. Electronics is a domain; its devices—capacitors, inductors, transistors—all work with electrons and thus naturally fit together. Likewise, in photonics, lasers, fiber-optic cables, and optical switches all manipulate light. Whereas an individual technology—say, the jet engine—is designed for a particular purpose, a domain is "a toolbox of useful components"—"a constellation of technologies"—that can be applied across many industries. A technology is invented, Arthur writes. A domain "emerges piece by piece from its individual parts."

The distinction is critical, he argues, because users may quickly adopt an individual technology to replace existing devices, whereas new domains are "encountered" by potential users who must try to understand them, figure out how to use them, determine whether they are worthwhile, and create applications for them. Meanwhile, those developing the new domains must improve the tools in the toolbox and invent the "missing pieces" necessary for new applications. All this "normally takes decades," Arthur says. "It is a very, very slow process."

What Arthur touches on just briefly is that this evolution of a new body of technology is often matched by an even more familiar progression: enthusiasm about a new technology, investor and user disillusionment as the technology fails to live up to the hyperbole, and a slow reëmergence

WWW Explore IPVision's interactive patent map of progress in microfluidics: **technologyreview.com/microfluidic**

as the technology matures and begins to meet the market's needs.

MICROFLUIDICS COULD MAKE POSSIBLE CHEAP AND PORTABLE DIAGNOSTIC DEVICES FOR USE IN DOCTOR'S OFFICES OR EVEN REMOTE CLINICS. BUT THE TECHNOLOGY HAS YET TO BE WIDELY ADOPTED.

A SOLUTION LOOKING FOR PROBLEMS

In the late 1990s, microfluidics (or, as it is sometimes called, "lab on a chip" technology) became another overhyped advance in an era notorious for them. Advocates talked up the potential of the chips. But the devices couldn't perform the complex fluid manipulations required for many applications. "They were touted as a replacement for everything. That clearly didn't pan out too well," says Michael Hunkapiller, a venture capitalist at Alloy Ventures in Palo Alto, CA, who is now investing in several microfluidics startups, including Fluidigm. The technology's capabilities in the 1990s, he says, "were far less universal than the hype."

The problem, as Arthur might put it, was that the toolbox was missing key pieces. Prominent among the needed components were valves, which would allow the flow of liquids to be turned on and off at specific spots on the chip. Without valves, you merely have a hose; with valves you can build pumps and begin to think of ways to construct plumbing. The problem was solved in the lab of Stephen Quake, then a professor of applied physics at Caltech and now in the bioengineering department at Stanford. Quake and his Caltech coworkers found a simple way to make valves in microfluidic channels on a polymer slab. Within two years of publishing a paper on the valves, the group had learned how to create a microfluidic chip with thousands of valves and hundreds of reaction chambers. It was the first such chip worthy of being compared to an integrated circuit. The technology was licensed to Fluidigm, which Quake cofounded in 1999.

Meanwhile, other academic labs invented other increasingly complex ways to manipulate liquids in microfluidic devices. The result is a new generation of companies equipped with far more capable technologies. Still, many potential users remain skeptical. Once again, microfluidics finds itself in a familiar phase of technology development. As David Weitz, a physics professor at Harvard and cofounder of several microfluidics companies, explains: "It is a wonderful solution still looking for the best problems."

There are plenty of possibilities. Biomedical researchers have begun to use microfluidics to look at how individual cells express genes. In one experiment, cancer researchers are using one of Fluidigm's chips to analyze prostate tumor cells, seeking patterns that would help them select the drugs that will most effectively combat the tumor. Also, Fluidigm has recently introduced a chip designed to grow stem cells in a precisely controlled microenvironment. Currently, when stem cells are grown in the lab, it can be difficult to mimic the chemical conditions in a living animal. But tiny groups of stem cells could be partitioned in sections of a microfluidic chip and bathed in combinations of biochemicals, allowing scientists to optimize their growing conditions.

And microfluidics could make possible cheap and portable diagnostic devices for use in doctor's offices or even remote clinics. In theory, a sample of, say, blood could be dropped on a microfluidic chip, which would perform the necessary bioassay—identifying a virus, detecting telltale cancer proteins, or finding biochemical signs of a heart attack. But in medical diagnostics as in biomedical research, microfluidics has yet to be widely adopted.

Again, Arthur's analysis offers an explanation. Users who encounter the new tools must determine whether they are worthwhile. In the case of many diagnostic applications, biologists must better understand which biochemicals to detect in order to develop tests. Meanwhile, those developing microfluidic devices must make the devices easier to use. As Arthur reminds us, the science and technology must build on each other, and technologists must invent the missing pieces that users want; it is a slow, painstaking evolution.

It's often hard to predict what those missing pieces will be. Hunkapiller recalls the commercialization history of the automated DNA sequencer, a machine that he and his colleagues invented at Caltech and that was commercialized in 1986 at Applied Biosystems. (The machine helped make possible the Human Genome Project.) "Sometimes, it is a strange thing that makes a technology take off," he says. Automated sequencing didn't become popular until around 1991 or 1992, he says, when the company introduced a sample preparation kit. Though it wasn't a particularly impressive technical advance—certainly not on the level of the automated sequencer itself—the kit had an enormous impact because it made it easier to use the machines and led to more reliable results. Suddenly, he recalls, sales boomed: "It wasn't a big deal to pay $100,000 for a machine anymore."

In a recent interview, Whitesides demonstrated a microfluidic chip made out of paper in which liquids are wicked through channels to tiny chambers where test reactions are carried out. Then he pulled a new smart phone, still in its plastic wrapping, out of its box. What if, he mused, you could somehow use the phone's camera to capture the microchip's data and use its computational power to process the results, instead of relying on bulky dedicated readers? A simple readout on the phone could give the user the information he or she needs. But before that happens, he acknowledged, various other advances will be needed. Indeed, as if reminded of the difficult job ahead, Whitesides quickly slipped the smart phone back into the box. TR

DAVID ROTMAN IS EDITOR OF *TECHNOLOGY REVIEW*.

SOCIAL MEDIA

True Match

HOW DOES THE MATCHING ALGORITHM OF THE POPULAR DATING SERVICE SUGGEST POTENTIAL MATES?

By EMILY GOULD

"Find Love. Guaranteed." –*Match.com tagline*

I have a friend–let's call her "Ruby"–whose dating life has lately experienced a dry spell. Worse than a dry spell, actually–more like a dry spell interrupted by intermittent acid rain. Things reached a crisis late one night, and in a fit of defeated desperation, she got out her credit card and pressed the button that sent $39.99 to Match.com, securing her a one-month membership with the online dating service. She told me of her decision the next day, and began a month-long quest for love through online dating. Naturally, I was suspicious of the whole endeavor from the start, but at the time I could not adequately explain why Match.com seemed so sketchy.

"Their ads are lame," I told Ruby (some of whose experiences described here are actually those of other friends of mine; I was keen to protect her anonymity). "You're young and beautiful, and you live in a city! Why are you wasting your time on strangers?" But Ruby grew up in the Midwest and has never managed to shake the conviction that dogged work is correlated to success in all realms, and she was determined to apply herself strenuously to dating on Match.com.

She tweaked her profile and searched countless men's profiles, exchanging e-mails and meeting up with the most likely-seeming specimens several days a week. At one point, she even sacrificed a weekend morning to have a coffee date with a PhD student in Continental philosophy who didn't ask her a single question about herself. As the month progressed, her standards became lower. Men who cropped their profile pics at the eyebrows to exclude their retreating hairlines were no longer off limits. But as Ruby went downmarket and reset her "what I'm looking for" settings accordingly, she succeeded only in increasing the quantity of her miserable dates. At the end of the month, she was forced to admit defeat. But we were left wondering how America's most popular for-fee dating site, which boasts that it attracts 20,000 new members a day, had failed Ruby.

WWW.MATCH.COM

Curious about the site's matching algorithm, I set up my own profile. Because I already knew what a woman's experience on Match was like, I posed as a male version of myself. I bumped my height up two inches and used a rather nebbishy-looking Facebook friend's profile photo as my own.

The resulting persona, SensitiveDude450, was a five-foot-nine-inch, "athletic and toned" 27-year-old Jew with an annual salary in the mid five figures. He liked yoga and cats. And while some women did look at his profile during the month I spent on the site, no one ever sent him an e-mail or even a "wink."

To be fair, SensitiveDude450 was not exactly putting himself out there. Proffered "mutual matches," he declined to e-mail them. But these matches, and the "Daily 5" (selected by the site's "advanced matchmaking service," which prompts the user to check out the day's matches and select "yes," "no," or "maybe" for each profile), did contain some clues as to how matching works–and I needed clues, because no one who works at Match would speak to me for this review, on the not-unreasonable grounds that the site's methodology is proprietary. The short answer to the question "How does match-

ISTVAN BANYAI

ing work?" seems to be: "Not the way it pretends to work."

SensitiveDude had not expressed any preferences when it came to the height, ethnicity, salary, or body type of his potential dates. "Surprise me!" I thought.

But in the first batch of suggested dates, the matches seemed to have less in common with the Dude than with each other. That set included a short 23-year-old Jewish woman with a cute photo of herself at a fancy restaurant and two others of herself on the arms of guys. She liked the *Economist* but also *Us Weekly*. Her favorite things included "brunch." The site said we had been matched because we were both dog lovers, eldest children, and athletic and toned.

The second match, too, the site said, was deemed compatible on the basis of birth order and pet preferences. But I noted that she was also Jewish, also young (24), and also short, at five foot two. "Seats at a Yank's *[sic]* game are always a winner with me," her "About Me" section declared. This assertion was reinforced by a photo of her in a jersey at a baseball game. Another photo showed her posing in panties and a tank top.

I clicked "maybe" when the site asked me to say whether I was interested in her, and then I clicked "maybe" on a couple of the other short young Jews—not wanting to click "yes," which would have automatically informed the women of my interest. But one woman who'd been shown my profile in her top 5 did click "yes," so I checked her out.

She was a 24-year-old lab tech at a fertility clinic, with an incoherent, heavily misspelled profile. She loved malls and hated country music, and her profile photograph was an odd shot of her sucking on a straw. The site, seeming desperate to find something we had in common, pointed out, "Like you, she's never been married!" I looked at my own profile to remind myself that I was no prize, but then I shut my laptop. I was beginning to understand the basis of the distrust I'd felt when Ruby joined Match. It was gross to know that actual men sat there as I'd just done, flipping through photos of women so desperate for their attention that they posted photos of themselves in bathing suits, twisting around to accentuate their butts while delivering soft-porn smiles.

All this is big business. Online dating, according to Forrester Research, produced $957 million in revenue in 2008—making it the third-largest generator of online paid-content revenue, after music downloading and gaming—and is expected to grow another 10 percent annually through 2013. Even (or especially) in the face of economic contraction, Match.com is thriving.

PACKAGED GOODS

As a man on Match, I had the sense that what I was doing was a kind of online shopping, which makes sense. The site uses the same type of data-mining technique, called latent semantic indexing (LSI), that search engines like Google use to rank the relevance of Web pages.

The trick behind successfully matching people and products—or people and other people, or people and other people who've packaged themselves into something like products by means of "profiles"—is math. "You and I don't imagine four-dimensional spaces, but mathematics and computers can," says David Jacobs, a vice president at the blogging-platform company SixApart, who's worked with similar technology in designing social-media sites. "Each additional attribute considered creates an extra dimension in the 'space' with which Match.com is looking for matches. The algorithm creates a virtual graph which approximates hundreds or thousands of axes."

That's straightforward. But the other half of the trick is not: it has to do with analyzing the way customers browse rather than the rankings and feedback they deliver. It's the difference between recommending a match for SensitiveDude450 because we're "both eldest children" and recommending a match because the site knows that users like SensitiveDude click on the profiles of women who make a bit less money, are shorter, and share the same religion.

"Each of those companies invests heavily in R&D to try and find 'cheats' [that they use as] a competitive advantage," says Jacobs. "They can't ever share details, because they consider it a secret sauce. Also, my guess is that these cheats are not along single vectors, although ethnicity would probably be straightforward to identify as something that people would claim not to care about when, of course, they did."

By "cheats," Jacobs doesn't mean that Match's developers have automated their insights about who tends to like whom. More likely, the programmers use an algebraic tool called singular-value decomposition, or SVD, which has many applications in statistics. Match.com's computers are ignorant of the qualities that humans are thinking of when they use terms like *religion* or *body type*. Instead, they recognize patterns: SVD assigns values to the likelihood that two users with various combinations of stated preferences and characteristics will think each other a good match.

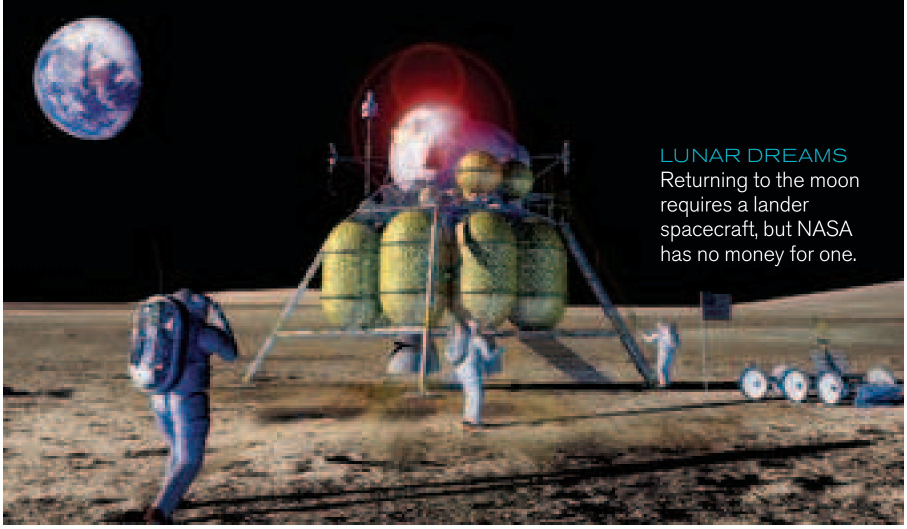
After Jacobs had filled me in on LSI, it made sense that the explanations Match gave me ("You share a birth month!") were simplifications. It generated them after it found a match by observing whose profiles I spent the most time reading and whose profiles other users like me have liked, among any number of other factors.

It's creepy, the idea that a computer can suss out what it is that SensitiveDude really wants—or at least, what he would be looking for if he existed. The only thing that makes it less creepy is that, at least in Ruby's case, all that predictive technology turned out—over and over again—to be wrong.

More time spent on the site might have paid dividends for Ruby: the site would have gotten to know her better. Lately, though, she has been searching the offline world for matches. This approach has its upside. For starters, you can wait until after you've actually met someone to show him what you look like in a bikini. TR

EMILY GOULD IS A FORMER EDITOR AT GAWKER.COM.

NASA



LUNAR DREAMS
Returning to the moon requires a lander spacecraft, but NASA has no money for one.

POLICY

The Future of Human Spaceflight

ARE ASTRONAUTS CLOSE TO EXTINCTION?

By JEFF FOUST

The International Space Station (ISS) is one of the most complex and expensive engineering projects ever undertaken. When it is completed in 2011, it will have cost nearly $100 billion. And then, just five years later, the space station will be destroyed when NASA deliberately takes it out of orbit and plunges it into Earth's atmosphere.

That, at least, is NASA's current plan. The agency would like to keep the station running, but funding for it is projected only through 2015, much to the consternation of researchers who are just beginning to use it and international partners who have invested billions of dollars in the project. Extending the life of the station would cost $2 billion to $3 billion a year. Even "deorbiting" it—dumping its remains safely into the ocean—will not be cheap, costing at least $2 billion.

REPORT OF THE U.S. HUMAN SPACEFLIGHT PLANS COMMITTEE

The 2015 deadline means that after decades of largely directionless space policy, Congress will be forced to make at least one clear decision: it must allocate funds for either the space station's continued operation or its destruction. And that is just one of a number of urgent issues facing the country's human spaceflight program. The space shuttle is due to be retired by late 2010 or early 2011, leaving NASA without a means of sending astronauts anywhere for several years. And the key elements of NASA's exploration program, the Ares I rocket that will launch astronauts into orbit and the Orion capsule that will ferry them around in space, are several years behind schedule.

In October, the Augustine Committee, a panel chartered by the White House and chaired by former Lockheed Martin CEO Norman Augustine, issued its report on the future of space travel. The committee examined NASA's plans and explored alternatives. Much of the report discussed the merits of different destinations in space and the rocket and spacecraft technologies that could be used to reach those destinations. But embedded in the report is a rationale for why there should be a human spaceflight program at all. "The Committee concluded that the ultimate goal of human exploration is to chart a path for human expansion into the solar system," it states.

Over the years, NASA and space advocates have put forward many reasons to justify sending astronauts into space. They have garnered support by offering something for everybody, especially the military and scientific communities; scientific progress, strategic superiority, and international prestige have been foremost among the promised benefits. On closer inspection, though, these justifications don't hold up or are no longer relevant. For example,

robotic missions are increasingly capable of scientific work in space, and they cost far less than human crews. Satellites launched on expendable boosters allowed the United States to achieve strategic dominance in space. And Cold War motives disappeared with the collapse of the Soviet Union.

Consequently, some have concluded that there is no longer any reason for human space exploration. A longtime critic of human spaceflight was the late James Van Allen, who in 1958 made the first major scientific discovery of the space age: the radiation belts around Earth that bear his name. In a 2004 essay, Van Allen wondered whether robotic spacecraft had made human spaceflight "obsolete." "At the end of the day," he wrote, "I ask myself whether the huge national commitment of technical talent to human spaceflight and the ever-present potential for the loss of precious human life are really justifiable."

But for most of the engineers and astronauts involved in the space program, astronauts can never be rendered obsolete by robots, because human spaceflight is an end in itself. They share the committee's belief that the purpose of these manned missions is to allow people to expand into, and ultimately settle, outer space.

For taxpayers who may well consider that prospect a pipe dream or the stuff of science fiction, the question is why their money should be spent to support it. The argument for funding human space exploration becomes similar to the argument for funding fundamental research: that doing so sometimes pays off big, usually in unexpected ways. By definition, high-risk ventures such as space exploration or curiosity-driven science seem unlikely to succeed and have unpredictable outcomes, but just such ventures have led to many inventions and discoveries with vast economic and historic significance.

Those who want a consistent long-term policy must reconcile their agendas, either supporting the rationale of settling space or coming up with an even better unifying purpose of their own. This must happen soon, or NASA's human space program will sputter to a halt. The committee put it bluntly: "The U.S. human spaceflight program appears to be on an unsustainable trajectory."

IF PEOPLE ARE GOING TO LIVE AND WORK IN SPACE, WE MUST TEST TECHNOLOGIES AND HUMAN PERFORMANCE UNDER LONG-TERM CONDITIONS. THE ISS IS THE IDEAL LABORATORY.

That has been true for some time. In early 2004, President Bush unveiled his strategy for continuing the U.S. space program. Key milestones included completing the ISS and retiring the space shuttle by 2010, developing what would become known as the Orion and Ares I by 2014, and returning humans to the moon by 2020, with long-term but undefined plans beyond that for human missions to Mars.

But Bush failed to provide a clear, unifying rationale for these plans, and they never received full funding. Under a constrained budget, the projects outlined by Bush will take years longer than originally planned. An example is the Ares V heavy-lift rocket needed for human missions to the moon. The current plan calls for it to be ready in the late 2010s, but the committee found that it could not be completed before the late 2020s—and even then there would be no money to develop the necessary lander spacecraft.

Using the Augustine Committee's rationale, however, we can make a reasonable plan based on the fundamental goal of human expansion into the solar system. With the goal of the space program clarified, money can be better spent and performance can be measured in concrete terms; Congress is far more likely to provide sufficient funding over the long term if it can see along the way that judiciously spent money is yielding tangible results. One of the first, and easiest, decisions to make is to extend the life of the ISS until 2020. If people are going to live and work in space for prolonged periods, we must test technologies and evaluate human performance under those conditions, and the ISS would be the ideal laboratory. Moreover, keeping the station operating will preserve an important international partnership for future missions.

One of the challenges in extending the life of the space station is that once the shuttle is retired, the Russian Soyuz spacecraft will be the only means of transporting crews to and from orbit until Ares I and Orion are ready, theoretically in 2015 (the committee believes that 2017 is more likely). The Augustine report suggests that NASA should get out of the business of shuttling astronauts back and forth and let the commercial sector provide transport to the station. The hope is that companies, serving NASA and other customers (such as space tourists and even other governments), can replace the shuttle sooner and at lower cost than NASA could, freeing up money for exploration.

The report also strongly endorses technology that NASA has largely overlooked to date: in-space refueling. With that capability, we wouldn't have to develop extremely expensive rockets, like the Ares V, that would be large enough to carry all the propellant needed for a trip to the moon. Fuel tanks—and thus the rockets themselves—could be smaller. Commercial operators could transport propellant and even maintain in-orbit fuel depots. The necessary technologies, the committee found, could be demonstrated in space within a few years.

If America's space community can't agree on this approach and thus secure the needed funding, the Augustine Committee concludes, it would be better to stop sending humans into space rather than wasting money and perhaps lives on a program that has no chance of success: "The human spaceflight program ... is at a tipping point where either additional funds must be provided or the exploration program first instituted by President Kennedy must be abandoned, at least for the time being." TR

JEFF FOUST IS THE EDITOR AND PUBLISHER OF THE *SPACE REVIEW.*

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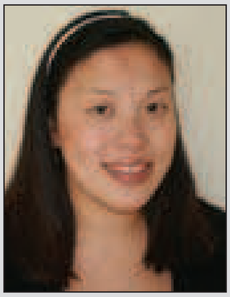
Career Growth Profile



IRENE POH

Age: 29

Job Title: Senior Business Analyst

Employer: Procter and Gamble

Graduate Programs: MBA, finance and strategy, University of Chicago, 2008; MEng, operations research and industrial engineering, Cornell University, 2002; BS, policy analysis and management, Cornell University, 2001

Like most undergraduates, Irene Poh wasn't sure what she wanted to be "when she grew up." One thing she did know, however, was that she was a "quant at heart." Quantitative subjects such as mathematics and statistics spoke to her. Poh felt strongly that her career would draw upon her passion for analysis.

Today, at age 29, she is a senior business analyst for Procter and Gamble, providing advisory and consulting services to P&G hair-care marketing teams across North America.

"I work with the various business leaders to provide strategic and tactical recommendations on how to solve some of their highest-priority business problems," Poh explains.

Poh attributes her solid footing in both qualitative and quantitative skills to her bachelor's degree in policy analysis and management and her master's degree in research and industrial engineering from Cornell University.

"Both degrees are about solving difficult programs and influencing decision makers and/or policy makers at critical moments," says Poh, who says her master's degree also helped her command a higher starting salary when P&G hired her straight out of school.

Three years into her career, however, Poh decided she needed more schooling, and a master's degree in business administration seemed to fit the bill.

"The business world is competitive, and education is an asset that nobody can ever take away from you," Poh says. "The University of Chicago is a very analytical program, with strengths in finance and economics. These were areas that supplemented my work in P&G's business analytics organization; I felt that I could benefit from the formal training in finance and business strategy."

To learn more about Irene's decision to continue her education—and how it helped her move up the corporate ladder, go to **www.technologyreview.com/careerresources/**.

Program Directory

HACK

How to Photograph the Earth

PHOTOS FROM NEAR SPACE FOR LESS THAN $150

By ERICA NAONE

EVERY ASTRONAUT talks about the awe of seeing the blue glow of Earth from orbit. Oliver Yeh and Justin Lee, both MIT students, wanted to see Earth from above, too. They built a contraption that was able to fly to the upper reaches of the atmosphere and take photographs from high enough up to show the planet's curvature and the blackness of space beyond. Though many devices have been built that could achieve this feat, their setup was uniquely inexpensive: it cost less than $150.

A BALLOON

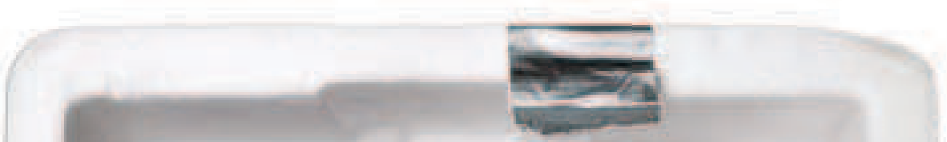
A weather balloon, which cost about $20, propelled the photo equipment to approximately 93,000 feet over about four hours. As planned, the thinning atmosphere then caused the balloon to pop, and the equipment descended in about 40 minutes with the aid of a parachute. To predict where it was likely to land, Yeh and Lee used a website maintained by the Department of Atmospheric Science at the University of Wyoming that assesses wind direction and strength. (They suggest that those who want to undertake similar projects inform the U.S. Federal Aviation Administration and check federal and local regulations first: strict laws govern the use of airspace above certain heights.)

B PARACHUTE

Yeh and Lee tested parachutes by attaching them to a styrofoam cooler filled with eggs and dropping it off the roof of a five-story building. Eventually, they found a design that allowed the eggs to land intact. They found that they could use a variety of materials to make the parachute—even a trash bag.

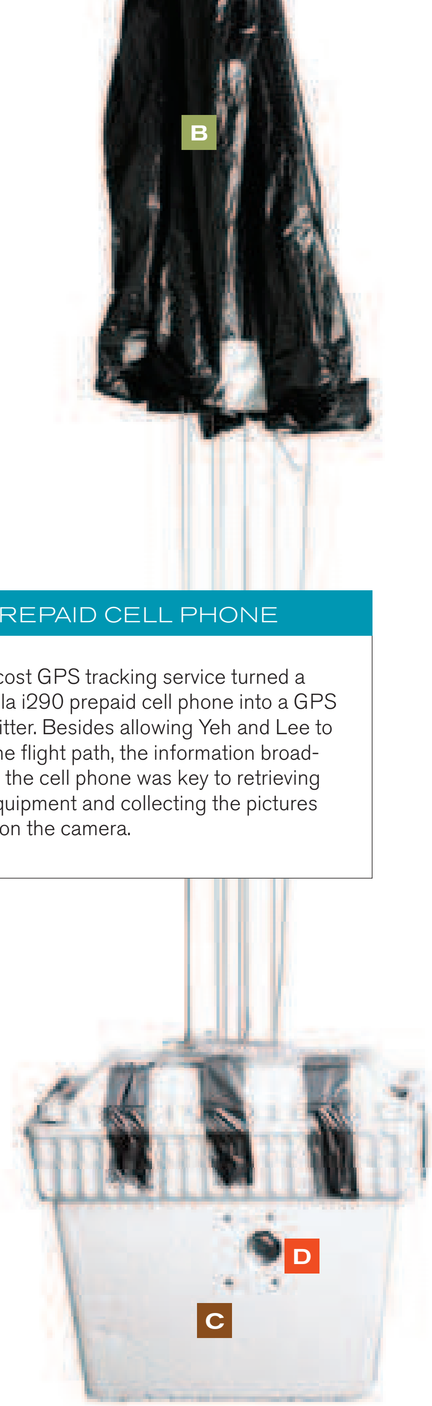
C STYROFOAM BEER COOLER

To keep the equipment from failing in the chill of the upper atmosphere, Yeh and Lee packed it in a protective cooler. For additional warmth, they insulated the camera and phone with newspaper and put chemical hand warmers next to each device. They carved a hole in the cooler for the camera's lens.



D CAMERA

Yeh and Lee modified an off-the-shelf Canon A470 camera by installing open-source software that instructed the device to snap a photo every five seconds. The images, covering almost five hours in flight, were stored on an eight-gigabyte memory card.



E PREPAID CELL PHONE

A low-cost GPS tracking service turned a Motorola i290 prepaid cell phone into a GPS transmitter. Besides allowing Yeh and Lee to track the flight path, the information broadcast by the cell phone was key to retrieving their equipment and collecting the pictures stored on the camera.

F BATTERIES

Lithium batteries designed to function down to −40 °C powered both the camera and the cell phone. The phone was also plugged into a battery-powered charger as backup during the flight.

WWW See the balloon take flight: **technologyreview.com/icarus**

BRUCE PETERSON

DEMO

Nervy Repair Job

DOUGLAS SMITH MECHANICALLY STRETCHES LIVING NERVES TO GROW RESILIENT TRANSPLANTS.

By KRISTINA GRIFANTINI

In a lab at the University of Pennsylvania, a plastic dish holds two rows of tiny black dots, pairs of them connected by dozens of thin, hairlike filaments. Each dot is a cluster of thousands of neurons, explains Douglas Smith, who is a professor of neurosurgery and the director of Penn's Center for Brain Injury and Repair. The fibers that stretch between them actually comprise thousands of axons, long, slender projections that conduct electrical impulses away from each neuron's central body. These bundles—each one a lab-engineered nerve—represent physical bridges that Smith hopes will help researchers like him mend previously irreparable injuries.

When sections of nerves in the body are severed or crushed, they die Although the nerves can regenerate, they do it at the glacial pace of about one millimeter a day. And there's another catch: as new axons grow, they need the original nerve sheath—a protective membrane made up of several different kinds of cells—to guide them to the area that has lost function. That sheath begins to disintegrate after about three months without a living nerve in it. "It's a race against time," says Smith. A nerve severed in, say, the wrist can span the short distance to the hand and heal in time to restore function. If the same nerve were cut near the shoulder, however, the person would almost certainly lose full use of that hand, since the new growth would not reach the hand before the sheath died.

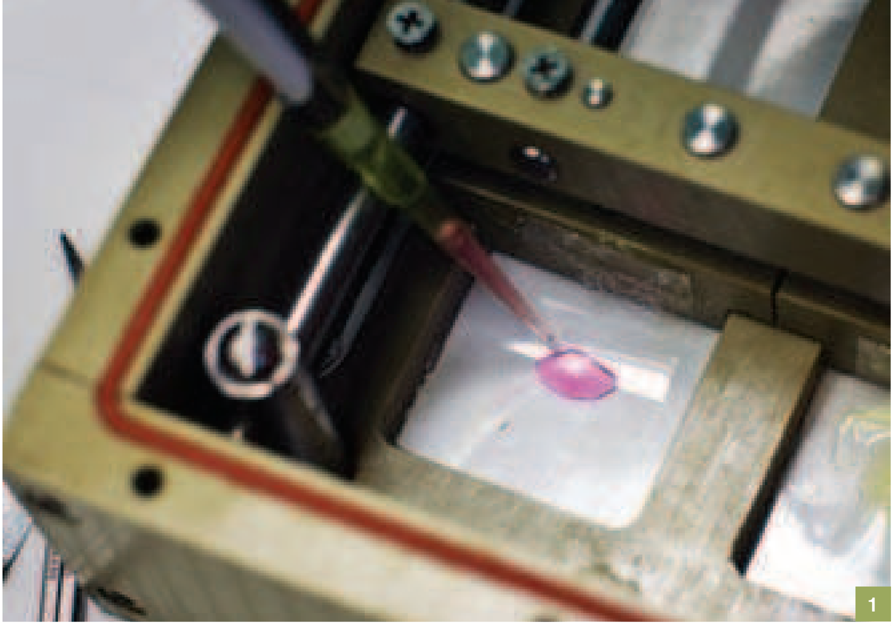
Not even the most advanced experimental techniques have been able to restore nerve function to sites far from an injury. Smith thought he might facilitate fast nerve regeneration by using lab-grown nerves as a kind of scaffold that doctors could place where a patient's nerve has died. Though the implanted nerve would not transmit signals itself, the presence of the living tissue could guide the body's regenerating nerve back to the injury site while keeping the detached nerve sheath intact.

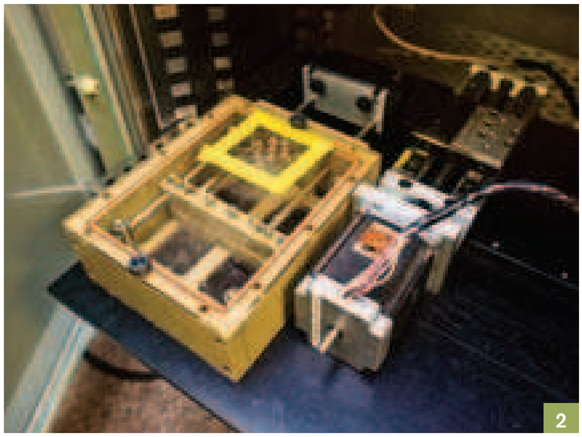
To get the engineered nerves to grow long enough to span the injured area by the time they were transplanted, he applied slight, gradually increasing physical tension; this process, he found, encouraged nerves to grow almost 100 times as fast as scientists had believed possible. And the nerves grew not just longer but also thicker, apparently because additional proteins form in response to the tension. Smith and his team introduced these engineered nerves into rats that had part of their leg nerves cut out. Within four months, as the natural nerves began to regenerate in the rats' bodies, the transplants had helped guide those nerves across the chasms, successfully restoring function to the rats' legs.

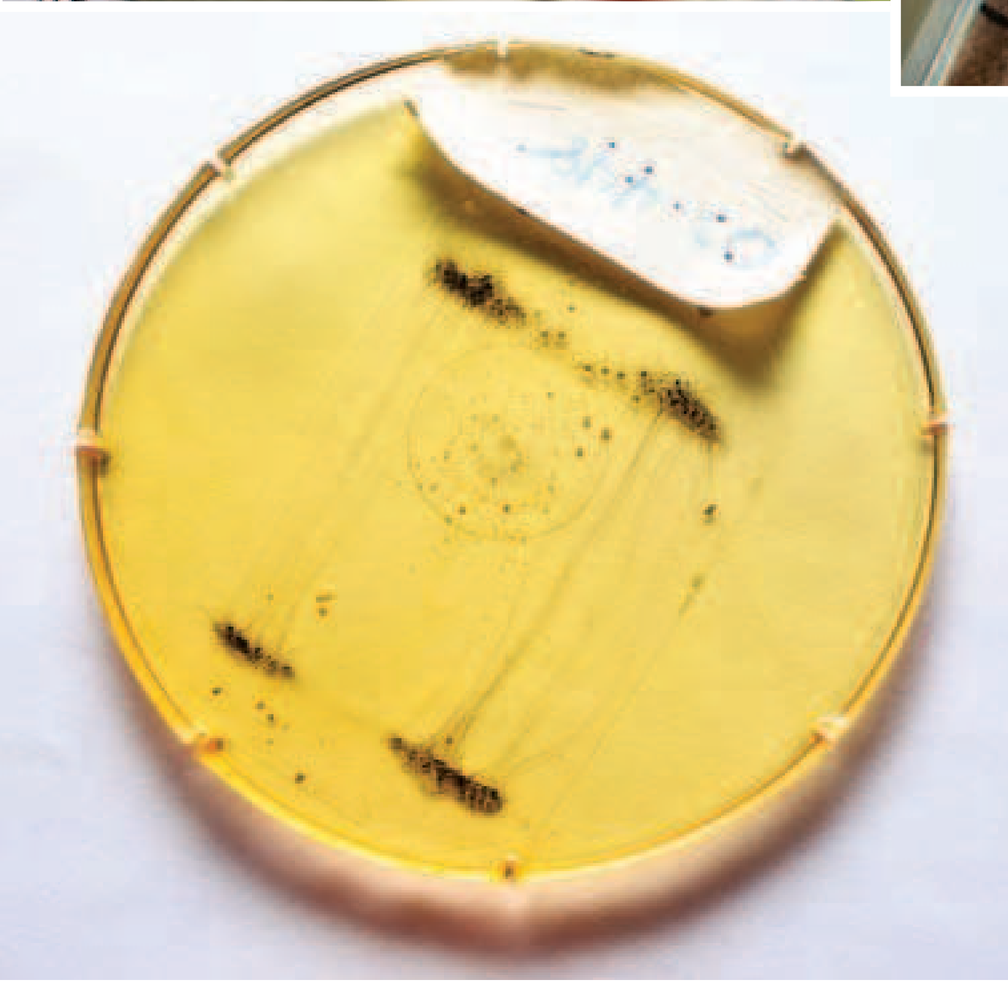
STRETCHING IT

To make the long nerve transplants, Smith and his team first collect sensory neurons—cells that transmit information to the brain—

PORTER GIFFORD





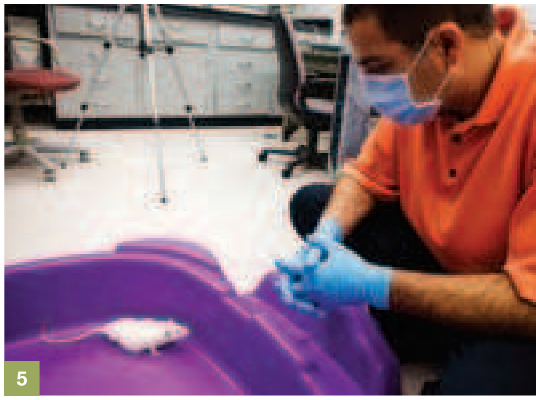


Opposite: At the University of Pennsylvania Center for Brain Injury and Repair, professor of neurosurgery Douglas Smith uses mechanical tension to speed the growth of implants that he hopes will repair nerve damage.
Left: In a plastic case, thin nerve fibers extend five centimeters between dark clusters of neurons.
1. Lab technician Kevin Browne pipettes pink collagen onto clear plastic membranes. The protein will serve as a medium for harvested nerve cells.
2. A custom-built stretching chamber is put inside an incubator and attached to a computer-controlled motor that slowly pulls one membrane away from the other, stretching the axons that connect the groups of nerve cells on each membrane.

from the spinal cords of fetal rats. Research technician Kevin Browne then pipettes a gelatinous pink protein called collagen onto two adjacent films in a specially built chamber. About the size of a shoebox, it houses a stretching apparatus made up of a vertical block attached to metal rods. One of the small, clear films, called the towing membrane, is suspended at one end by the block and curves down almost to the base of the chamber, where it overlaps the second membrane. Browne places one set of neurons in the collagen on the towing membrane and another on the bottom membrane. At this point, the two groups are less than 100 micrometers—two hairs' width—apart. He puts the whole setup into a humming incubator that runs at 37 °C, mimicking the internal temperature of a rat.

The next day, Browne drips a solution of enzymes and other proteins onto the membranes using a pipette; the solution encourages the neurons to sprout axons. Slowly, an axon from a single neuron reaches out and forms a synaptic connection with a neuron across the way. After about five days, the axons have securely connected to their neighboring neurons, and Browne attaches the chamber's rods to a computer-controlled motor. The motor pulls the towing membrane away from the bottom membrane at a varying rate that has been determined by trial and error.

After about three to five days of gradually increasing the tension, the team can begin stretching the axons as fast as one



3. Using tiny forceps, Browne carefully places the two groups of connecting neurons in this biodegradable polymer tube, which acts as a support structure. Once the lab-stretched nerve is inside, Browne seals the lengthwise opening shut with miniature surgical sutures.
4. Smith removes a piece of a rat's sciatic nerve, places the tube-enclosed nerves in the gap, and seals the tube in place.
5. After a few months, the rat's own nerve cells regrow through the living implant and find their way down to its foot, and the animal regains function in its leg.

centimeter per day (roughly 100 times the speed at which regenerating nerves grow in the body), though shorter transplants can be stretched more slowly.

REPAIR WORK

After about a week of slow stretching, Browne takes the elongation box out of the incubator. He uses a pipette to add more collagen, which acts like a soft glue, on top of the cells. Then he rolls the nerve fibers and the attached neurons off the films. With microscopic forceps, Browne drops the new nerve, now about a centimeter long, into a strawlike tube that has been split lengthwise. The tube, made of a biodegradable material that dissolves inside the body, serves as a synthetic nerve sheath. Browne sutures or glues it securely shut with the nerve inside.

In initial experiments designed to test the transplant's ability to repair nerve injuries, Smith removes about a centimeter of a rat's sciatic nerve, which runs through the buttocks and down the back of each leg to the ankle and foot, carrying messages from the spinal cord to the various leg muscles. He then places the tube into the space where the nerve was. Using forceps, he gently pushes a stump of the rat's sciatic nerve sheath into each end of the tube and seals it with fibrin glue. Without the implant in place, the part of the nerve sheath below the cut would degenerate, and the rat would lose movement in that leg. The lab-grown nerves provide a living pathway for regeneration, encouraging the rat's own motor neurons to grow in the right direction and keeping the sheath alive.

WWW Watch Smith explain how to stretch nerves and take a look inside his lab: **technologyreview.com/demo**

Smith says that in tests performed on more than 40 rats, his group has had almost 100 percent success at restoring the animals' ability to walk. When the researchers dissected those rats, they found that new axons had grown from their spinal cords and intertwined with the transplanted nerves. The neurons inside the tubes had also given rise to new axons that extended out of the tube in both directions and further mingled with the rats' own regenerating axons.

Smith and his team think that longer nerve implants could help repair more extensive injuries; so far, the longest nerve they have grown is approximately 10 centimeters. They have also shown that the stretching process works on human neurons from organ donors. Smith hopes to start testing the human-derived implants in patients with nerve injuries in the next two years. TR

PORTER GIFFORD; SURGERY PHOTO COURTESY OF UNIVERSITY OF PENNSYLVANIA

FROM THE LABS

BIOMEDICINE

Three-Dimensional Genome

NEW TECHNOLOGY REVEALS THE HIGHER-ORDER STRUCTURE OF DNA

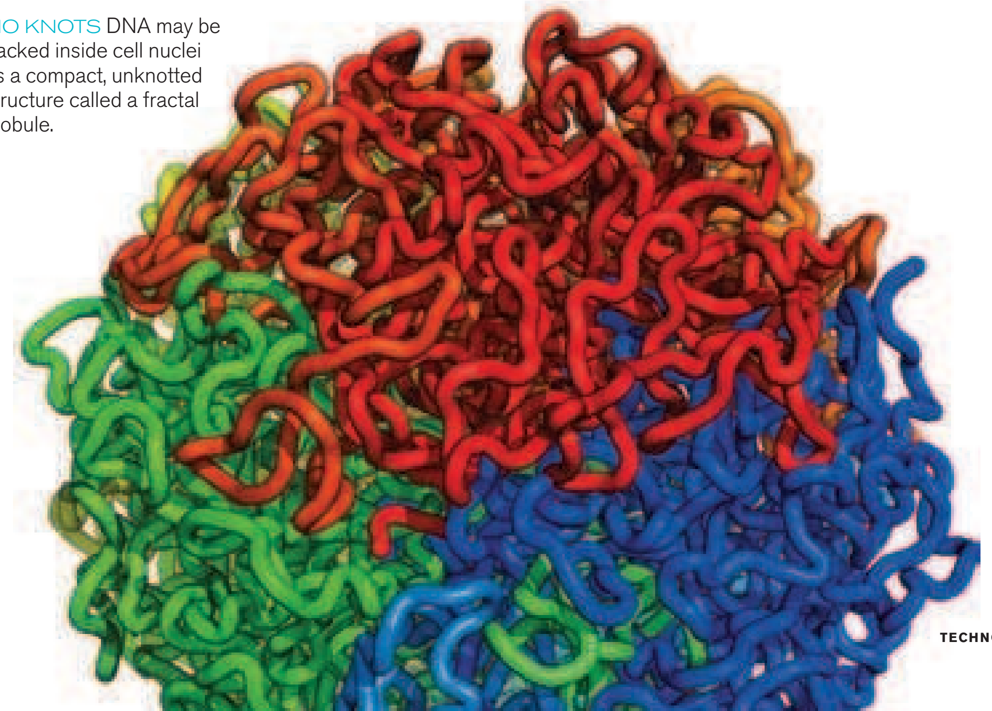
SOURCE: "COMPREHENSIVE MAPPING OF LONG-RANGE INTERACTIONS REVEALS FOLDING PRINCIPLES OF THE HUMAN GENOME"
Eric S. Lander, Job Dekker, et al.
Science 326: 289–293

Results: Scientists developed a tool that makes it possible to map the three-dimensional structure of the entire human genome, shedding light on how six feet of DNA is packed into a cell nucleus about three micrometers in diameter. According to the resulting analysis, chromosomes are folded so that the active genes—the ones this particular cell is using to make proteins—are close together.

Why it matters: Growing evidence suggests that the way the genome is packed in a particular cell is key to determining which of its genes are active. The new findings could allow scientists to study this crucial aspect of gene regulation more precisely.

Methods: Scientists treated a folded DNA molecule with a preservative in order to create bonds between genes that are close together in the three-dimensional structure even though they may be far apart in the linear sequence. Then they broke the molecule into a million pieces using a DNA-cutting enzyme. The researchers sequenced these pieces to identify which genes had bonded together and then used this information to develop a model of how the chromosome had been folded.

Next steps: Scientists plan to study how the three-dimensional structure of the genome varies between different cell types, between different organisms, and between normal and cancerous cells. They also hope that improving the resolution of the technology might reveal new structural properties of the genome. They can currently analyze DNA in chunks comprising millions of bases, but they would like to zero in on sequences thousands of bases long.



NO KNOTS DNA may be packed inside cell nuclei as a compact, unknotted structure called a fractal globule.

LEONID A. MIRNY AND MAXIM IMAKAEV/SCIENCE

Diabetic Cells

STEM CELLS DERIVED FROM PATIENTS WITH DIABETES PROVIDE A NEW MODEL FOR STUDYING THE DISEASE

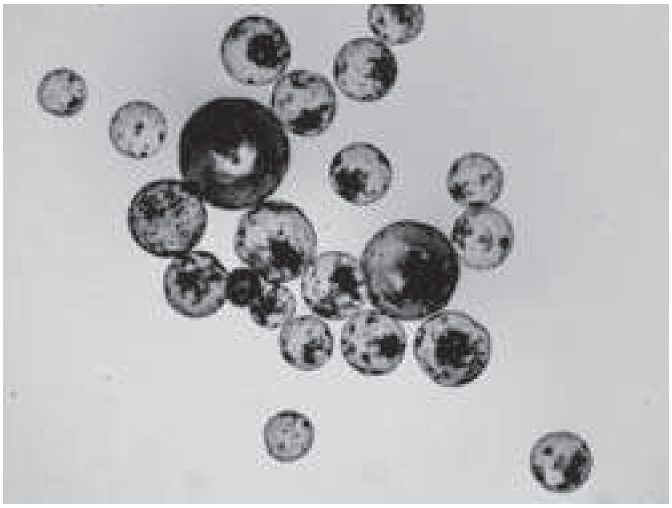
SOURCE: "GENERATION OF PLURIPOTENT STEM CELLS FROM PATIENTS WITH TYPE 1 DIABETES"
Douglas A. Melton et al.
Proceedings of the National Academy of Sciences 106: 15768–15773

Results: Scientists collected cells from patients with type 1 diabetes and turned them into induced pluripotent stem cells, adult stem cells with an embryonic cell's capacity to differentiate into many different cell types. Then they stimulated these cells to differentiate into insulin-producing pancreatic cells.

Why it matters: The stem cells carry the same genetic vulnerabilities that led the patients to develop diabetes. Watching them develop into insulin-producing cells should shed light on the development and progression of diabetes. Researchers may also be able to test new treatments on the developing cells.

Methods: Researchers "reprogrammed" skin cells from two diabetes patients by using a virus to insert three genes involved in normal development. The new genes caused other genes to turn on and off in a pattern more typical of embryonic cells, returning the skin cells to an earlier developmental stage. The scientists then exposed the cells to a series of chemicals, encouraging them to differentiate into insulin-producing cells.

Next steps: The researchers will examine the interaction between the different cell types affected by diabetes: the pancreatic beta cells and the immune cells that attack them. Initially they will study these interactions in a test tube, but ultimately they hope to incorporate the lab-generated human stem cells into mice. This will help scientists understand which cells are affected first. Armed with that knowledge, they could begin developing treatments that involve replacing some of those cells.



LIGHT-ACTIVATED These nylon capsules, filled with chemical reactants and carbon nanotubes, heat up and burst when irradiated with a laser.

MATERIALS

Nanotube Fibers

SUPERACIDS ARE THE KEY TO ASSEMBLING NANOTUBES INTO LARGE STRUCTURES

SOURCE: "TRUE SOLUTIONS OF SINGLE-WALLED CARBON NANOTUBES FOR ASSEMBLY INTO MACROSCOPIC MATERIALS"
Matteo Pasquali et al.
Nature Nanotechnology, published online November 1, 2009

Results: Rice University researchers have developed a way to arrange carbon nanotubes into large structures, including fibers hundreds of meters long, by dissolving them in a "superacid."

Why it matters: Assembling carbon nanotubes into well-ordered materials such as long fibers has proved challenging; though lining them up in a flowing solution seemed like a promising approach, nanotubes don't dissolve in conventional solvents. The new processing methods could be used to manufacture materials such as electrical transmission lines that are stronger and more conductive than the metal ones used today.

Methods: The researchers tried dissolving nanotubes in acids of varying strengths and found that in stronger acids, the tubes arrange themselves into a liquid crystalline phase in which they are well aligned. After developing a theoretical model to explain what conditions, including acid strength, are necessary to control the phase transitions, they were able to produce liquid crystal solutions that can easily be used to form long, high-quality fibers. Making them involves shooting the nanotube-acid mixture through a nozzle similar to a shower head and removing the acid with a coagulant, causing the nanotubes to bind together.

Next steps: To realize the promise of the assembly methods, researchers will need to develop ways to manufacture solutions of carbon nanotubes that have uniform properties. Transmission lines, for example, would need to be made from a batch containing mostly conducting nanotubes, with as few semiconducting nanotubes as possible.

Reactions on Demand

MICROCAPSULES ISOLATE REACTANTS UNTIL A LASER BURSTS THE BUBBLE

SOURCE: "CHEMICALS ON DEMAND WITH PHOTOTRIGGERABLE MICROCAPSULES"
Jean M.J. Fréchet et al.
Journal of the American Chemical Society 131: 13586–13587

Results: Researchers at the University of California, Berkeley, enclosed highly reactive chemicals in polymer microcapsules. They showed that the capsules can be burst using light from a laser, allowing the chemicals to escape and react with each other to form a desired product.

Why it matters: The microcapsules will enable chemists to place reactants in precise locations before triggering them to react. Scientists could also initiate reactions at precisely timed intervals. These techniques could be useful in applications such as timed drug delivery inside the body, printing, and self-healing materials.

Methods: The chemical to be encapsulated is mixed with a small quantity of carbon nanotubes and with the chemical precursors of nylon, which form nylon microspheres as the mixture is stirred. As they form, the spheres capture the nanotubes and the chemical reactant. When the researchers shine a red laser on the capsules, the nanotubes absorb the energy and heat up until the capsules burst. In a proof-of-concept experiment, the researchers made microcapsules that contained a special catalyst and suspended them in a reactive liquid. The microcapsule protected the catalyst and the liquid from reacting; however, when a laser was used to burst the capsules, the catalyst was released and quickly transformed the liquid into a solid.

Next steps: The group is testing reaction capsules that contain dyes instead of nanotubes to absorb the laser energy; the dyes respond to specific bandwidths of light, such as red, green, or blue. This could allow scientists to control reactions more precisely by shining different colors of light at different times.

STEFAN PASTINE AND DAVID OKAWA

ASSISTED REPAIR A United States Marine uses an augmented-reality headset to find and start a repair inside a light armored vehicle (left). The headset overlays text and illustrations on what he sees (right).

2009, STEVEN HENDERSON AND STEVEN FEINER, COLUMBIA UNIVERSITY

INFORMATION TECHNOLOGY

Virtual Repair

AUGMENTED REALITY HELPS MECHANICS FIX VEHICLES

SOURCE: "EVALUATING THE BENEFITS OF AUGMENTED REALITY FOR TASK LOCALIZATION IN MAINTENANCE OF AN ARMORED PERSONNEL CARRIER TURRET"
Steven J. Henderson and Steven Feiner
IEEE International Symposium on Mixed and Augmented Reality, October 19–22, 2009, Orlando, FL

Results: An "augmented reality" system developed by researchers at Columbia University helped mechanics with the United States Marines repair a light armored vehicle. Mechanics wearing the system's head-mounted displays were able to locate and begin each task in about half the time it would take to do so using a repair manual on a laptop computer, which is the conventional approach.

Why it matters: The system could make the repair process faster and more efficient. Similar equipment could eventually help civilian car mechanics or consumers.

Methods: To identify what part of the vehicle a mechanic is looking at, the researchers installed 10 cameras that track the positions of three infrared light-emitting diodes attached to the headgear, which reveal its position and orientation. The system uses this information, combined with a 3-D computer model of the interior of the vehicle, to automatically update the display as the mechanic looks around. Arrows appear on the screen to direct the mechanic to parts in need of repair or maintenance. For complex tasks, it then displays additional visual information such as an animated 3-D model that shows how to use the tools required to complete the task.

The researchers compared the performance of six mechanics as they used the augmented-reality system, an untracked headset displaying static information, and an LCD monitor that showed the same graphics. In tests, the mechanics started repair tasks in 56 percent less time when they used the augmented-reality system than they did when they used the untracked headset and in 47 percent less time than they did using the LCD monitor.

Next steps: The researchers want to improve the system so that it provides additional real-time feedback to help mechanics complete repairs more effectively. They would also like to incorporate the tracking sensors into the headset rather than relying on external cameras, which would allow the system to be used in other environments.

Automatic Defenses

A SYSTEM PROTECTS SOFTWARE BY DETECTING AND PATCHING ERRORS

SOURCE: "AUTOMATICALLY PATCHING ERRORS IN DEPLOYED SOFTWARE"
Jeff H. Perkins et al.
ACM Symposium on Operating Systems Principles, October 11–14, 2009, Big Sky, MT

Results: Software called ClearView automatically detected seven different types of attacks on the Internet browser Firefox and corrected the errors that the attacks exploited, all while the browser was running. It also ensured that the corrections didn't lead to other errors.

Why it matters: Security is a race between attackers and defenders. The researchers found that it takes nearly a month after an attack, on average, for human defenders to create a patch and get it in place. ClearView solves the problem within minutes, and the researchers say it could be optimized to work even faster.

Methods: The researchers programmed ClearView to monitor Firefox during operation and assemble a list of rules that describe the ordinary behavior of the binary machine code that executes instructions from the program's source code. ClearView then monitors the program for errors, such as an attempt by the browser to access a block of memory beyond what's been allocated to it by the operating system. When it finds an error, ClearView identifies which rule has been violated and then generates sets of instructions that force the browser to follow that rule. For example, if an error occurs because a URL entered into a browser is too long, a patch might check the length of URLs and chop off everything over the allowed length. The system uses statistical analysis to gauge which patches are most likely to work and then installs those patches to test their effectiveness. If additional rules are violated after one patch is installed, it rejects that solution and tries another.

Next steps: ClearView has been applied to errors that allow code injection attacks (those caused when an attacker introduces bits of malicious code into a program). The researchers are working on expanding the system to patch other kinds of errors. TR

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A Change in the Weather

RAINMAKING EFFORTS DURING THE VIETNAM WAR PROMPTED AN INTERNATIONAL BAN

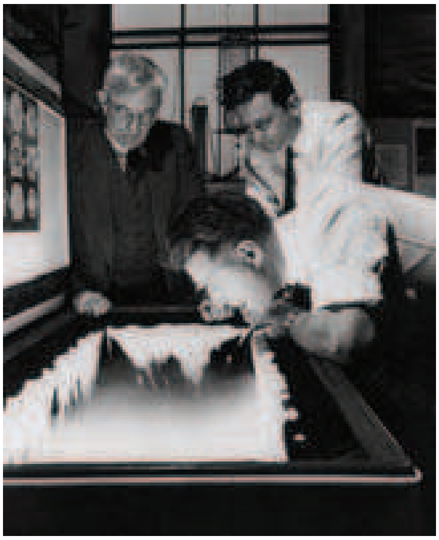
By MATT MAHONEY

After three years of dodging Senate inquiries, the Department of Defense, on March 20, 1974, presented a subcommittee of the Senate Committee on Foreign Relations with a briefing on the extensive rainmaking operations in Southeast Asia. The briefing was classified "Top Secret," but the hearing report was made public on May 19, 1974. In this way the American public officially learned for the first time that the United States had used a new and developing technology in an attempt to slow movement of North Vietnamese troops and supplies along the Ho Chi Minh Trail network. From March of 1967 until July of 1972 the Air Force had rained canisters of silver iodide into clouds, and these in turn were supposed to initiate an increase in rainfall.

So began geoscientist Gordon J. MacDonald's 1975 essay for *TR* on weather modification. Although the revelation of the Vietnam War program was the occasion for his article, his concerns were more general. MacDonald, who died in 2002, was then a professor at Dartmouth and had served on the President's Science Advisory Committee under Lyndon B. Johnson. Throughout his career, he was interested in the way the planet changes as a result of both natural processes and human interference. After World War II, it became clear that industrial activity was changing the world's climate. If humans were inadvertently creating climate change, it followed that they might be able to reverse those effects by modifying the local weather *(see "The Geoengineering Gambit," p. 50)*.

Weather modification moved from the realm of magic to an applied science in July of 1946 when Vincent Schaefer, then at the General Electric Laboratories, discovered that dry ice could bring about nucleation of super-cooled water into ice. These laboratory studies were extended by Irving Langmuir and Bernard Vonnegut, who discovered that silver iodide as well as dry ice acted as an effective agent in bringing about the transformation of super-cooled water into ice.

The laboratory work was soon supplemented by field observations. In November of 1946, Schaefer flew into a cloud over Pittsfield, Massachusetts, at an altitude of 40,000 feet and a temperature of -20 °C. After dispatching several pounds of dry ice into the clouds, Schaefer observed draperies of snow falling below the clouds.



RAIN MEN At General Electric, Irving Langmuir and Bernard Vonnegut watch as Vincent Schaefer tries to turn his breath into crystals.

SCHENECTADY MUSEUM; HALL OF ELECTRICAL HISTORY FOUNDATION/CORBIS

Governments took notice. At his inauguration, President John F. Kennedy pledged not only to "explore the stars" but also to "conquer the deserts"; he would later direct his science advisor, Jerome Wiesner, to pursue weather modification for humanitarian aims. But the scientists Wiesner consulted were uncertain how feasible weather modification would be and cautioned that international coöperation would be needed to ensure that the technology would not be used in war. The lure proved great, however, and rainmaking was used as a tactical weapon during the Vietnam War, albeit to minimal effect.

To some, rainmaking may seem relatively innocuous as compared with bombing or napalm. In some sense this is a correct view, but in the broader view the implications for future political stability are immense. We are developing a far more detailed understanding of the earth and its surroundings. ...

It may be possible in the future to trigger earthquakes with devastating results from a great distance, or to bring about major climatic changes by triggering the instabilities inherent in the Antarctic icecap. All of these possibilities seem today to be far-fetched. But our history has shown us that if a technology develops, it will be used, unless international agreements can be secured.

MacDonald didn't have to wait long. As the issue that contained his essay went to press, a proposal from the United States and the Soviet Union to ban the hostile use of environmental modification was put before the United Nations. Three years later, the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques entered into force. As the search for solutions to global warming grows more desperate, perhaps a new international consensus will be required. TR

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